What controls stratospheric water vapor?

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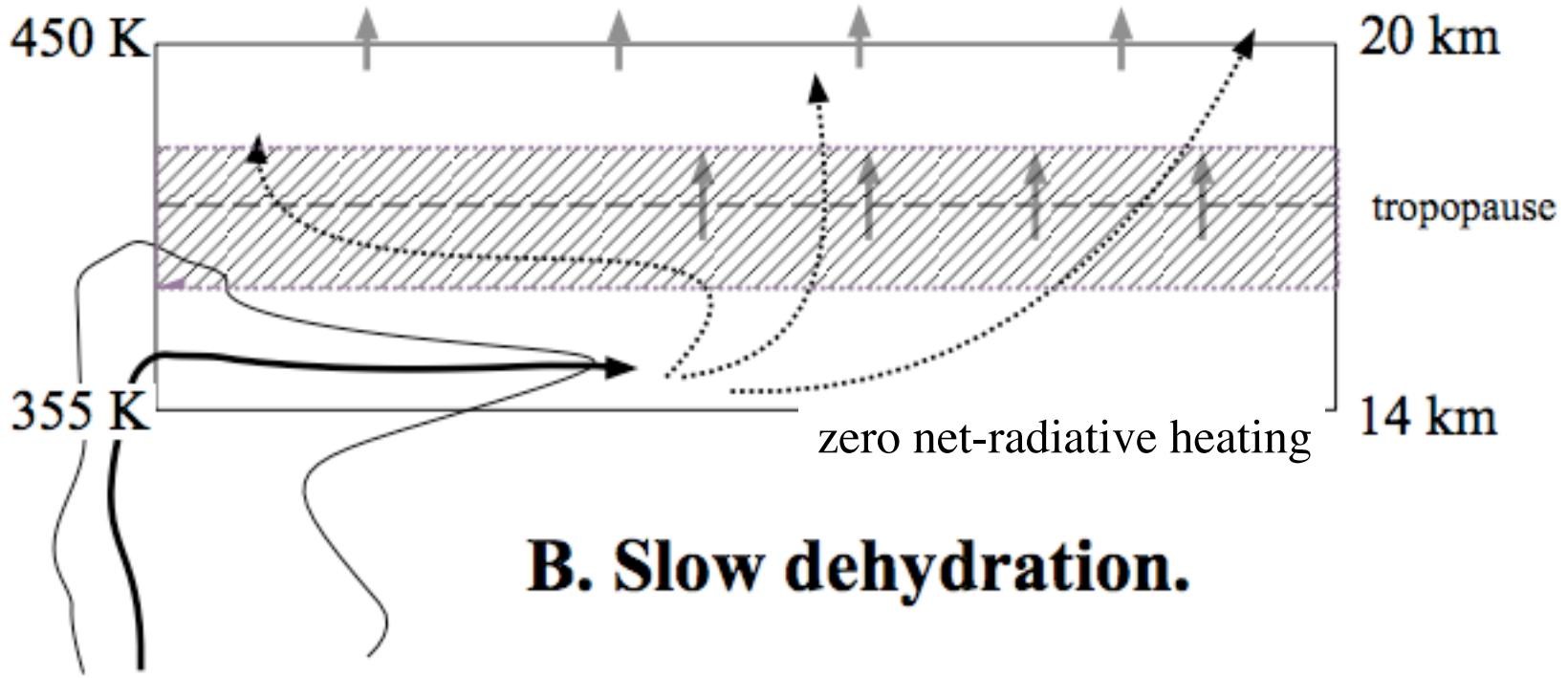
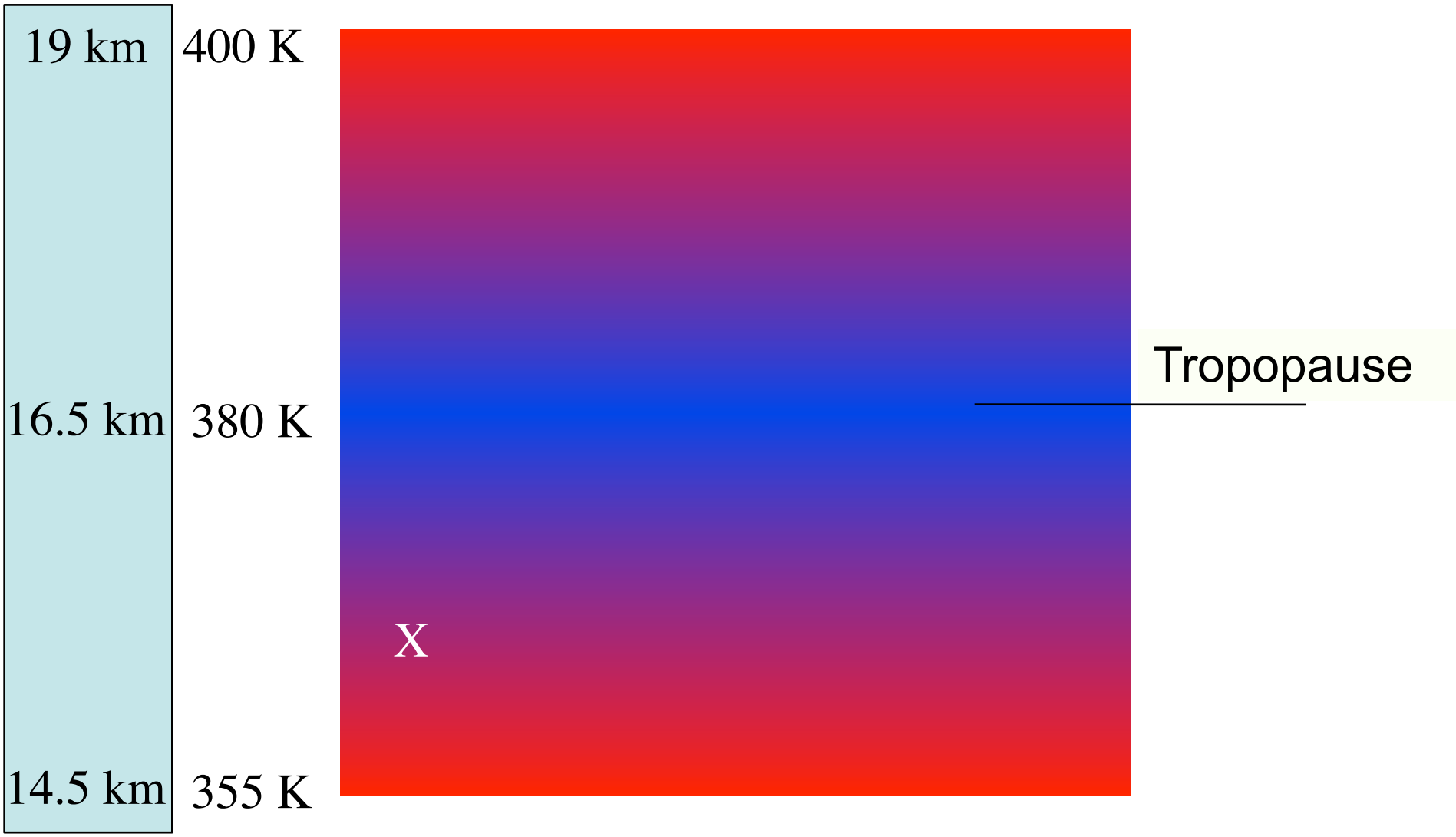
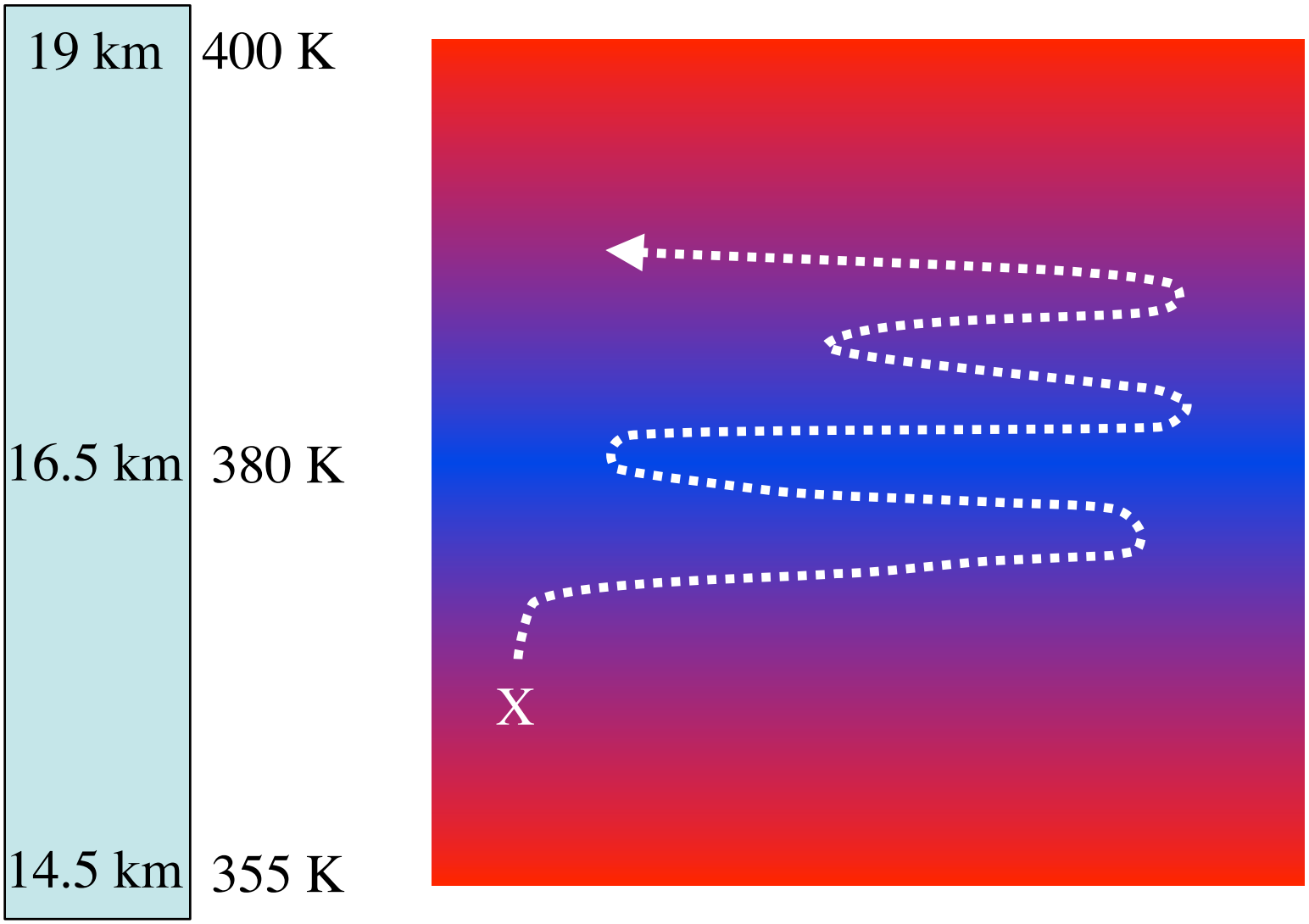
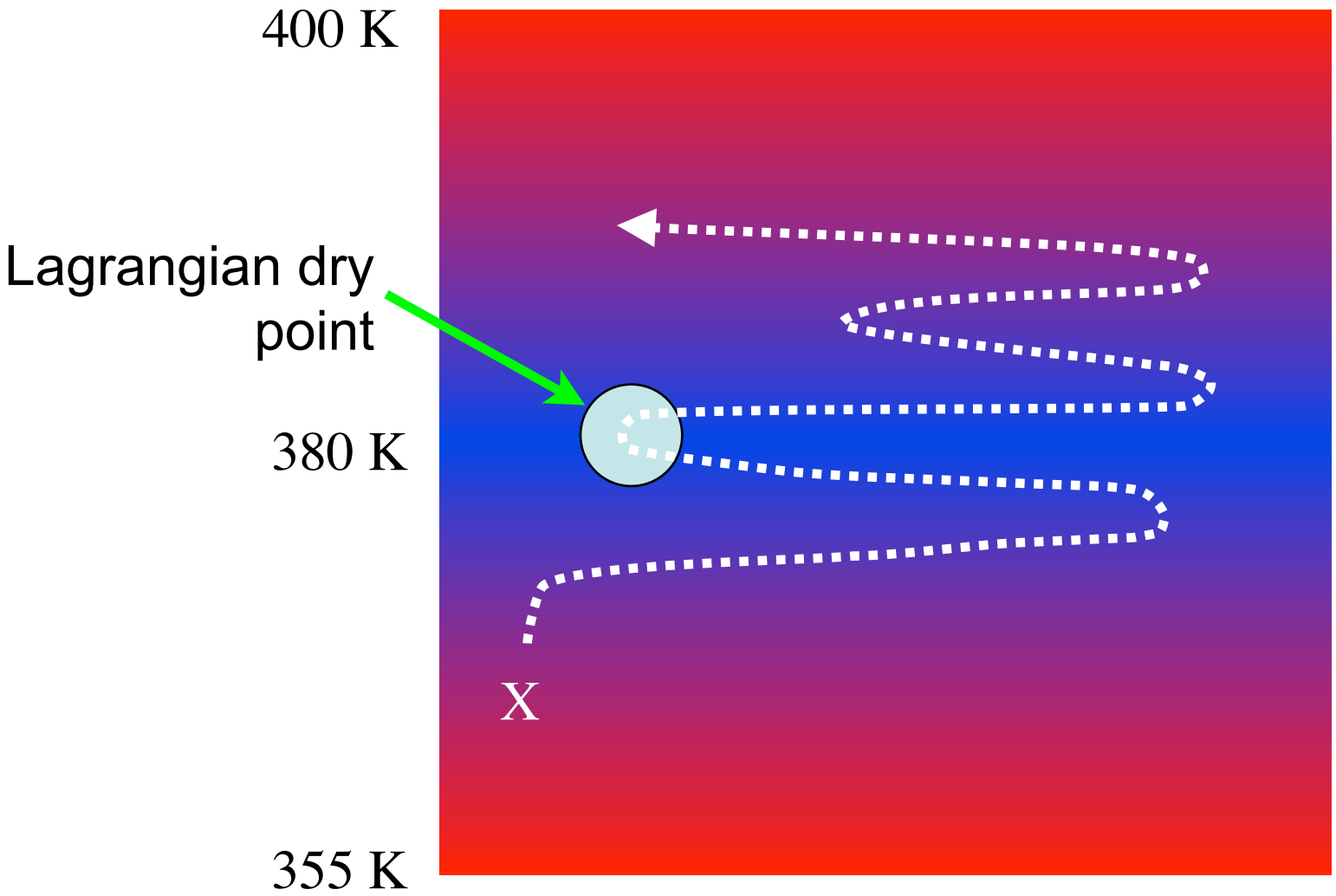
M.R. Schoeberl, T. Wang, S.M. Davis,
K.H. Rosenlof, J.-P. Vernier

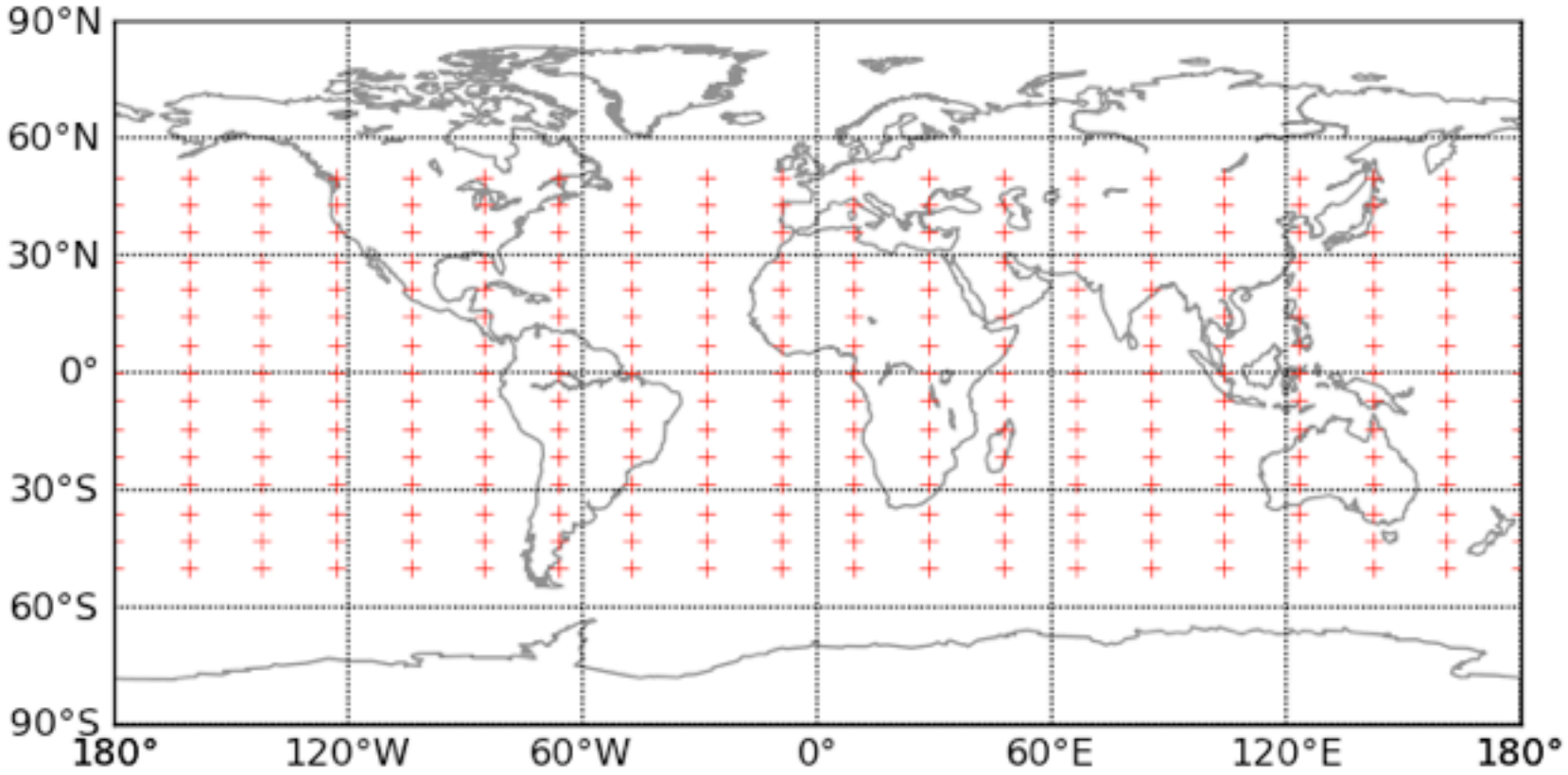
Sherwood and Dessler, 2000



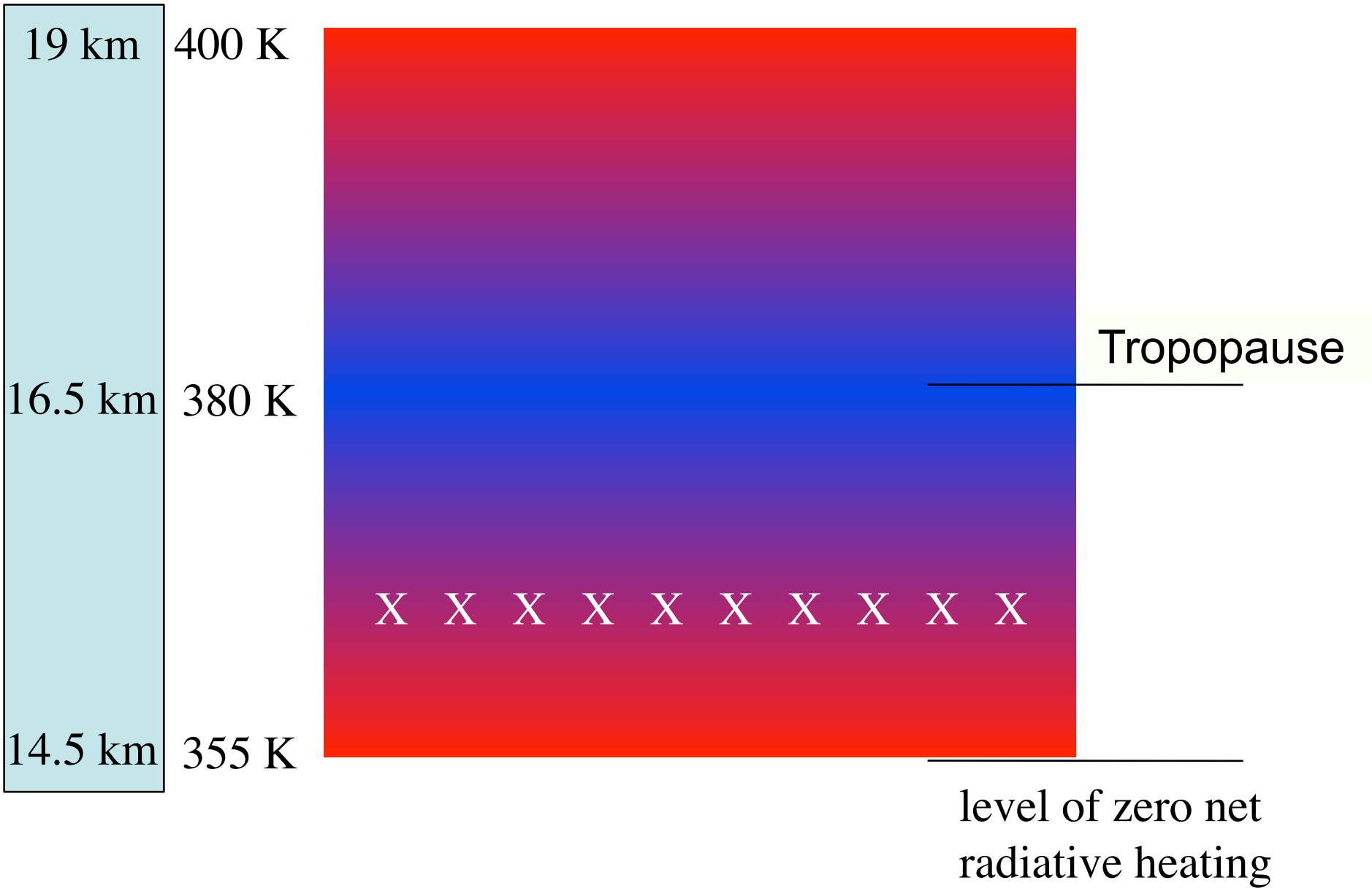

19 km
400 K
16.5 km
380 K
14.5 km
355 K
X
Tropopause

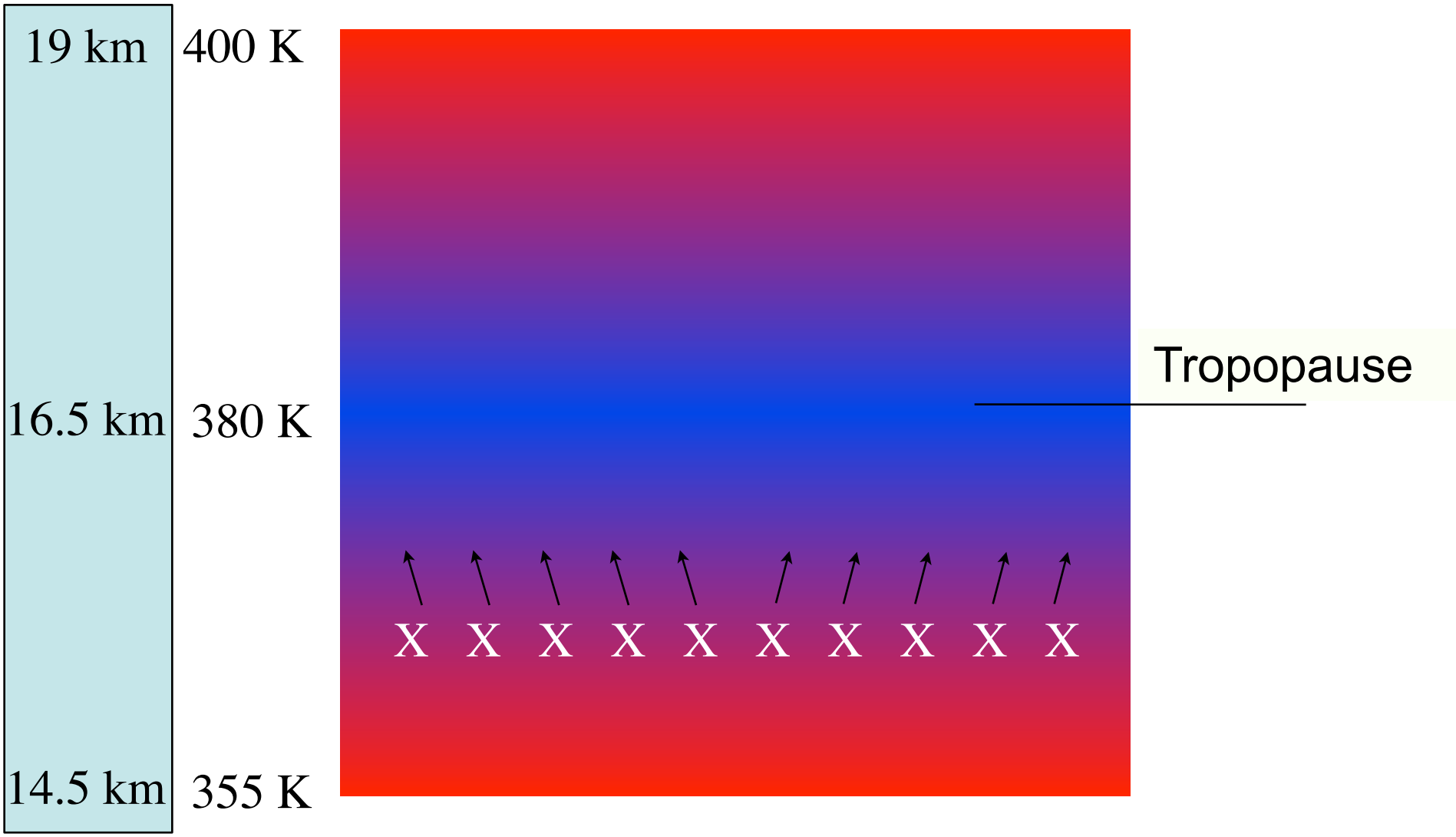

19 km
400 K
16.5 km
380 K
14.5 km
355 K
X

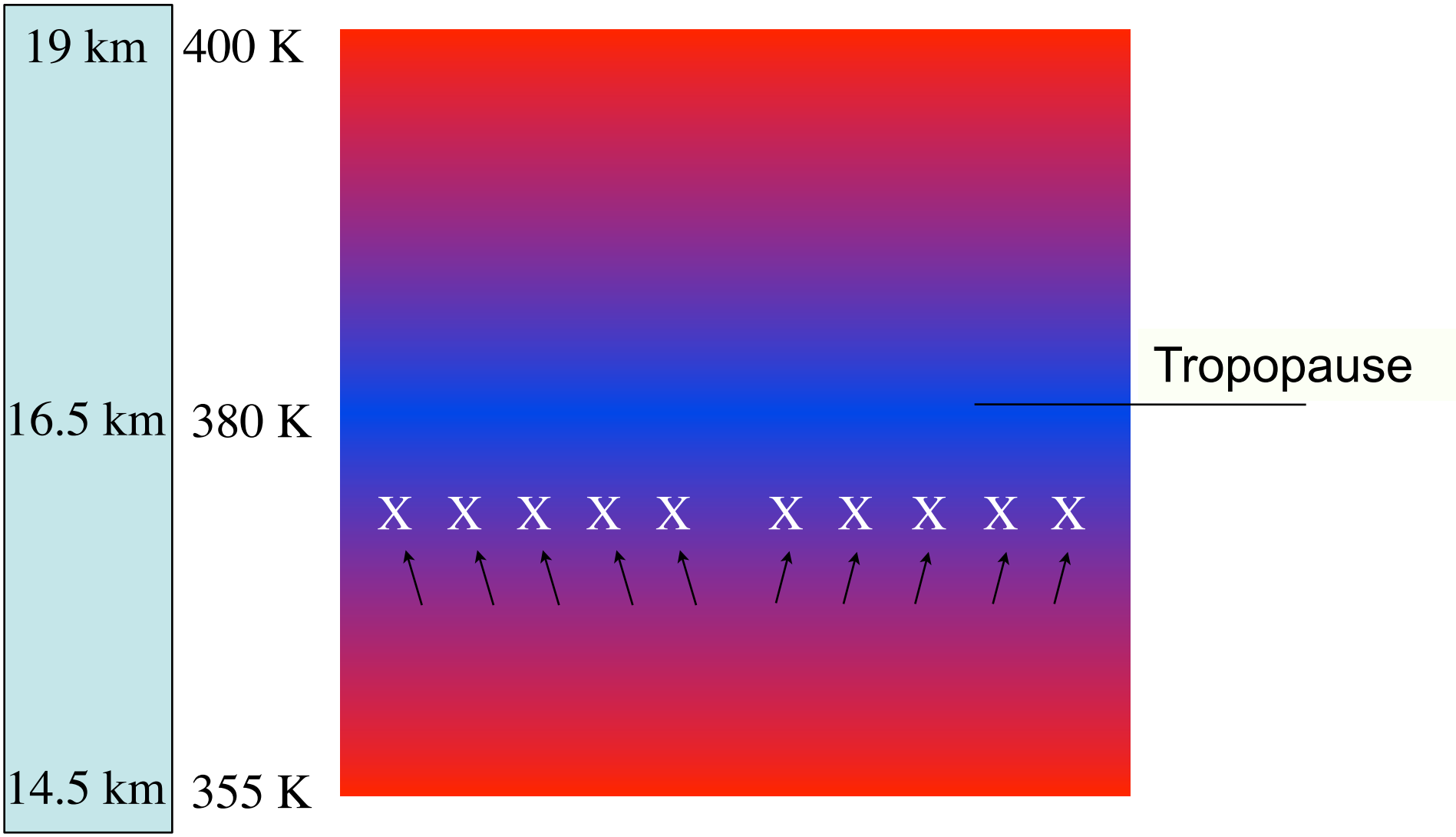

400 K
Lagrangian dry point
380 K
X
355 K

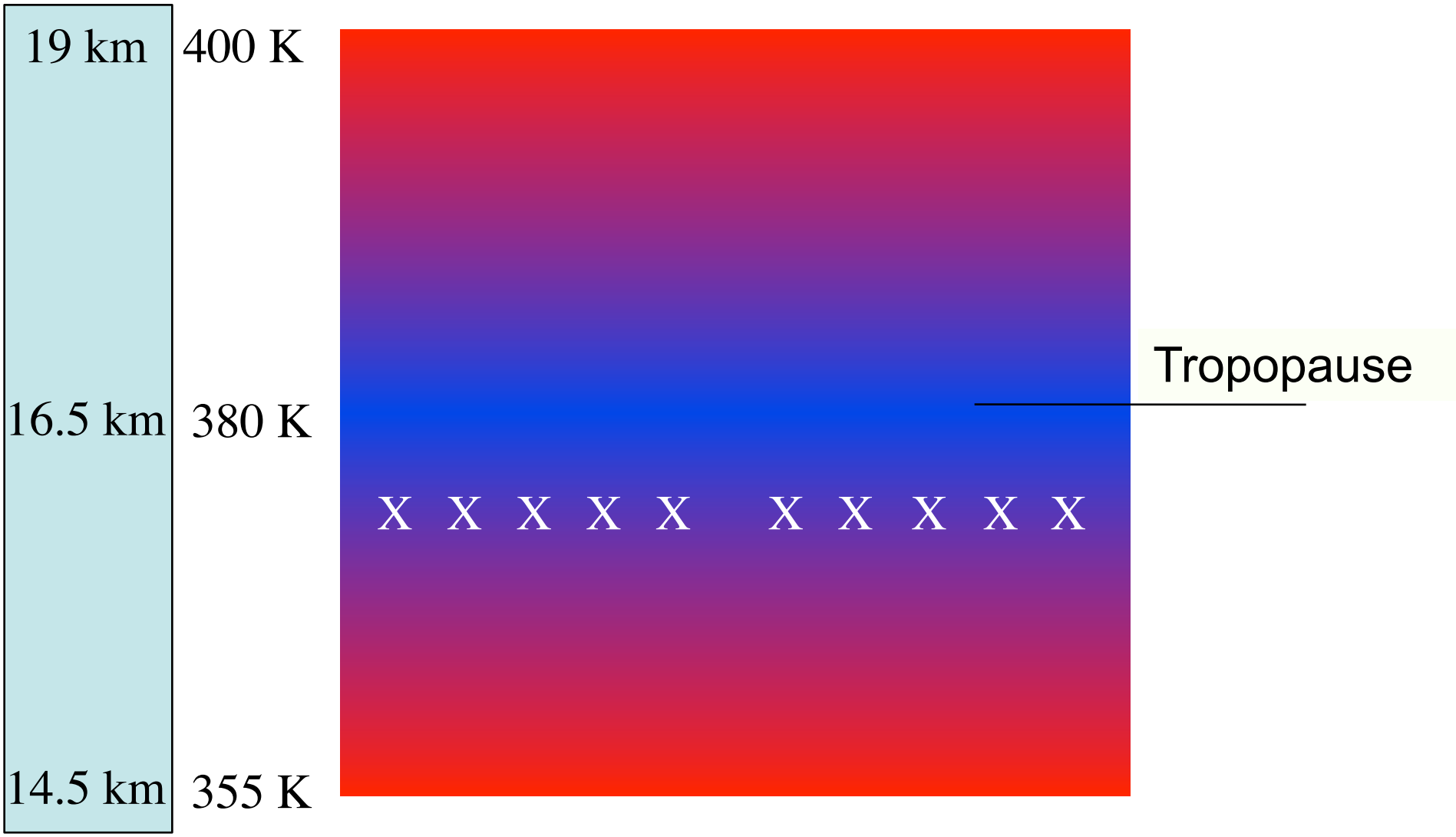


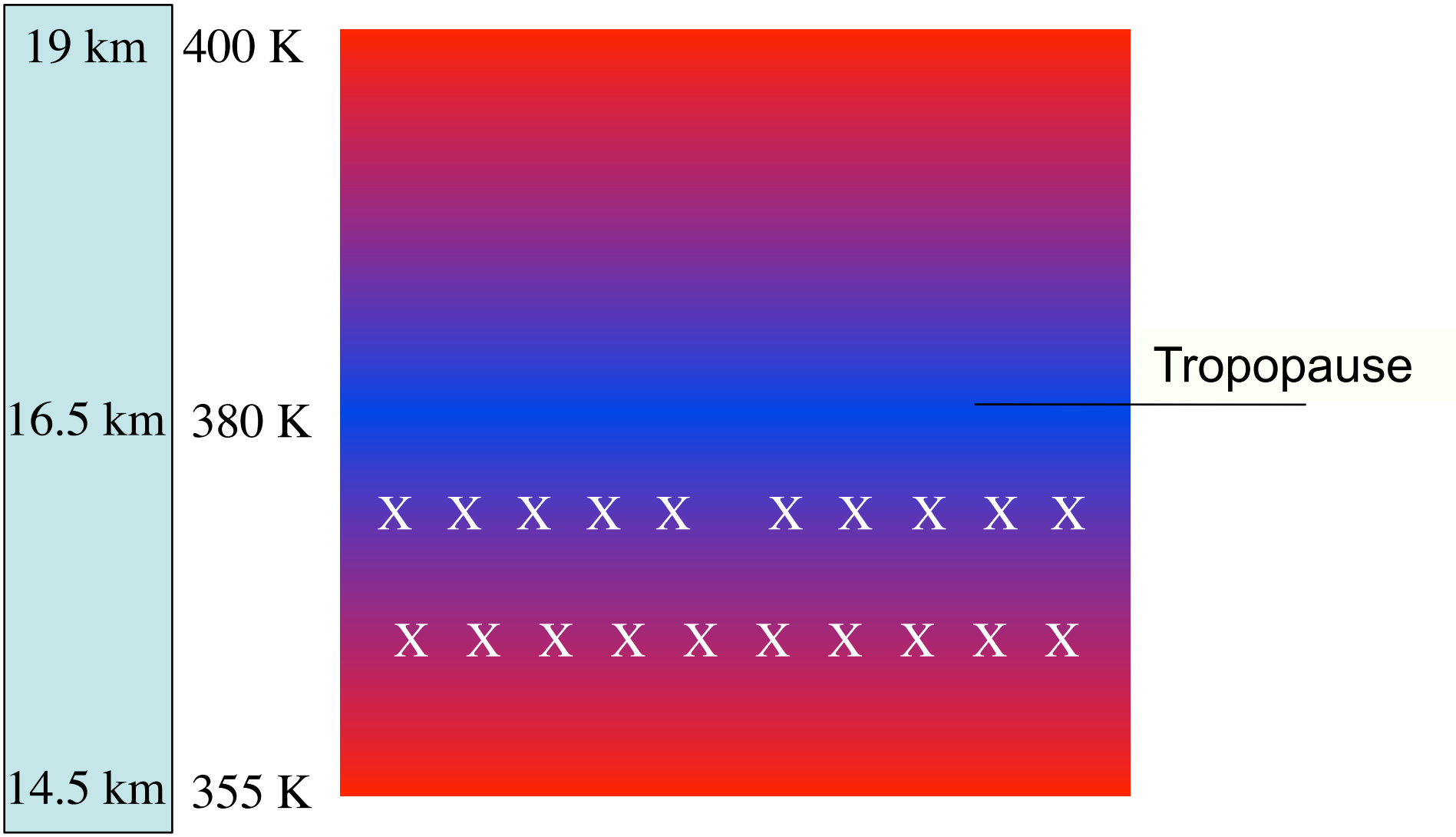
Parcels initialized at 365-K potential temperature

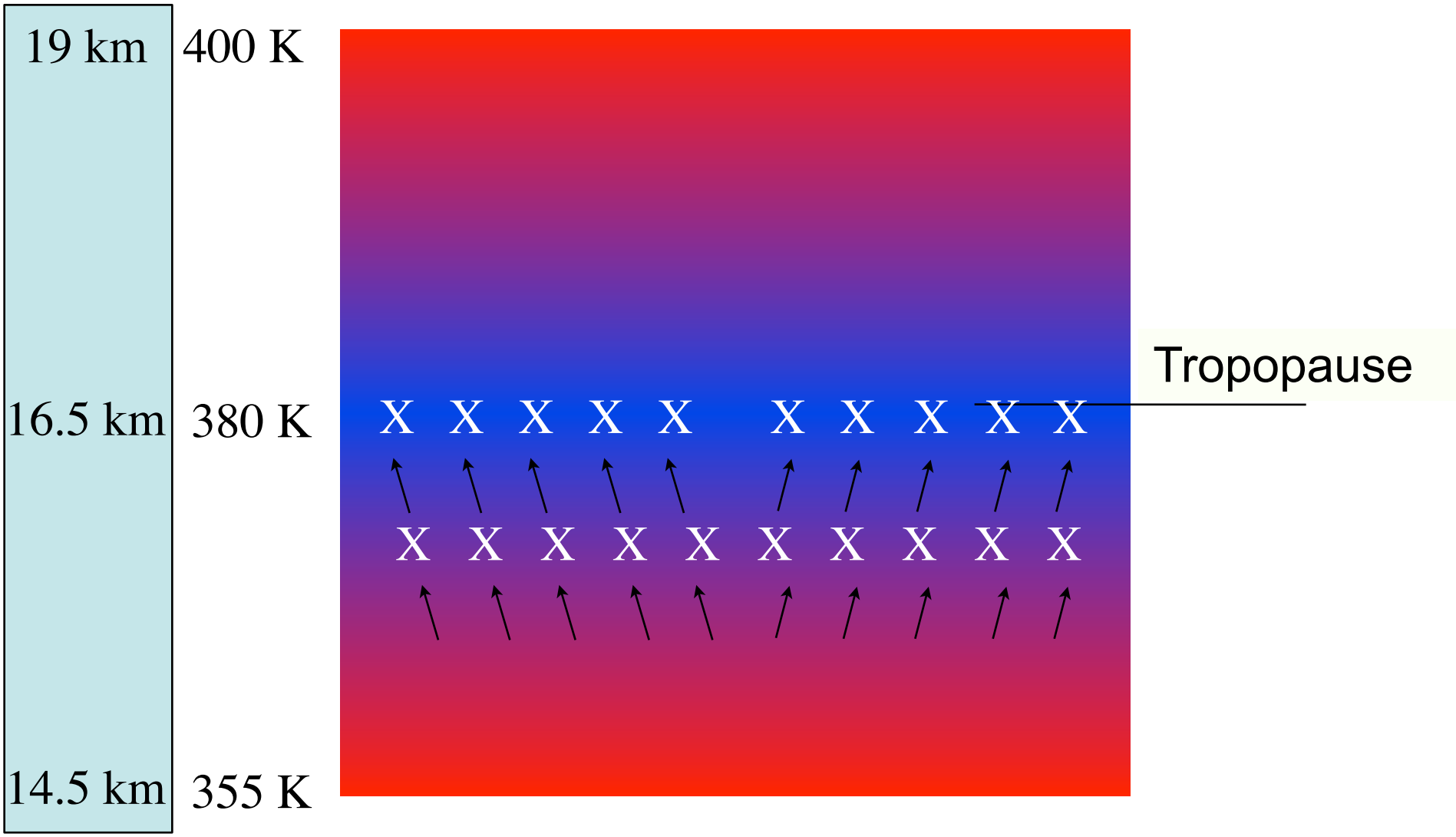

19 km
400 K
16.5 km
380 K
14.5 km
355 K
X X X X X X X X X X
Tropopause
level of zero net
radiative heating

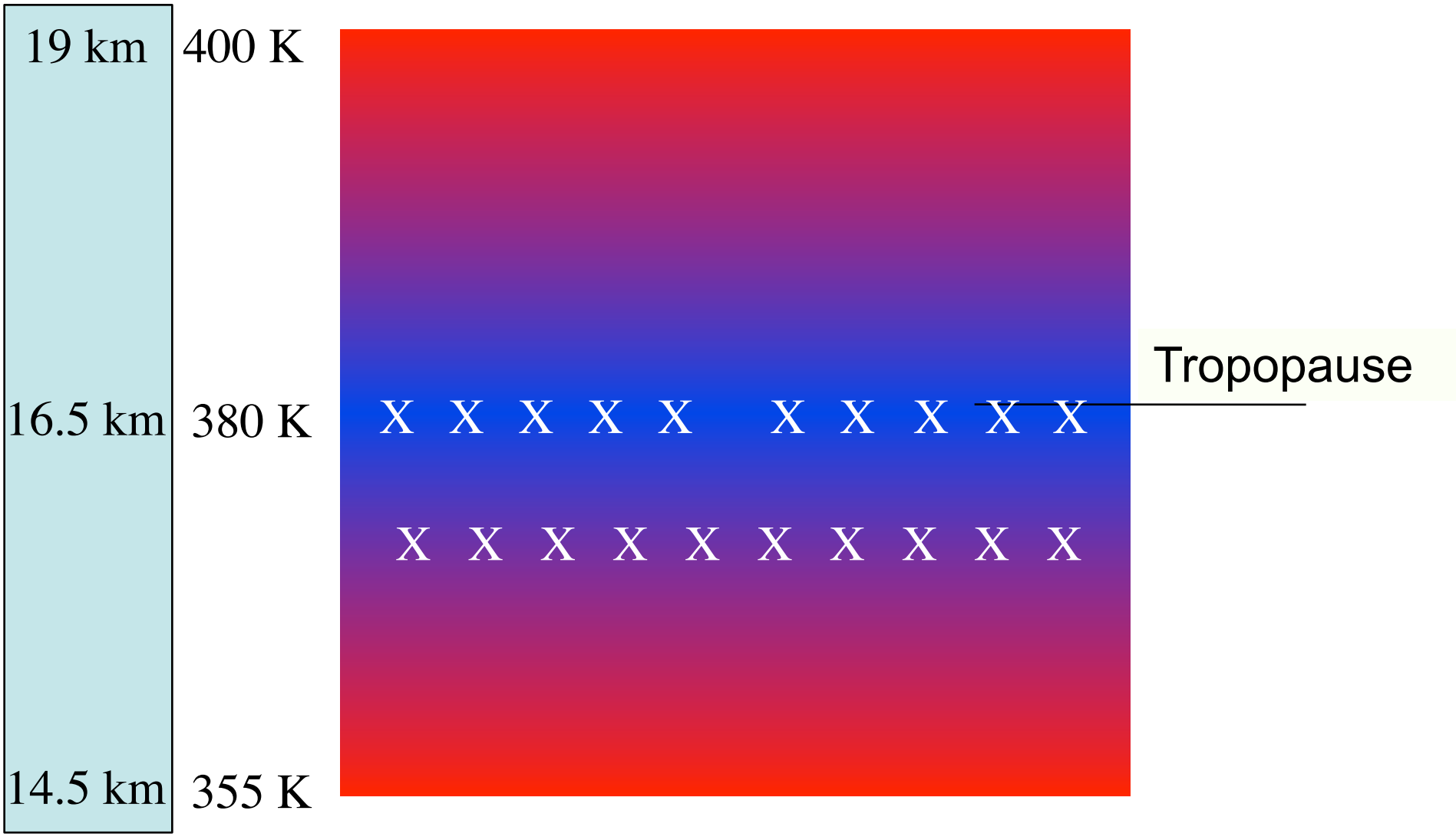

19 km
400 K
16.5 km
380 K
14.5 km
355 K
Tropopause

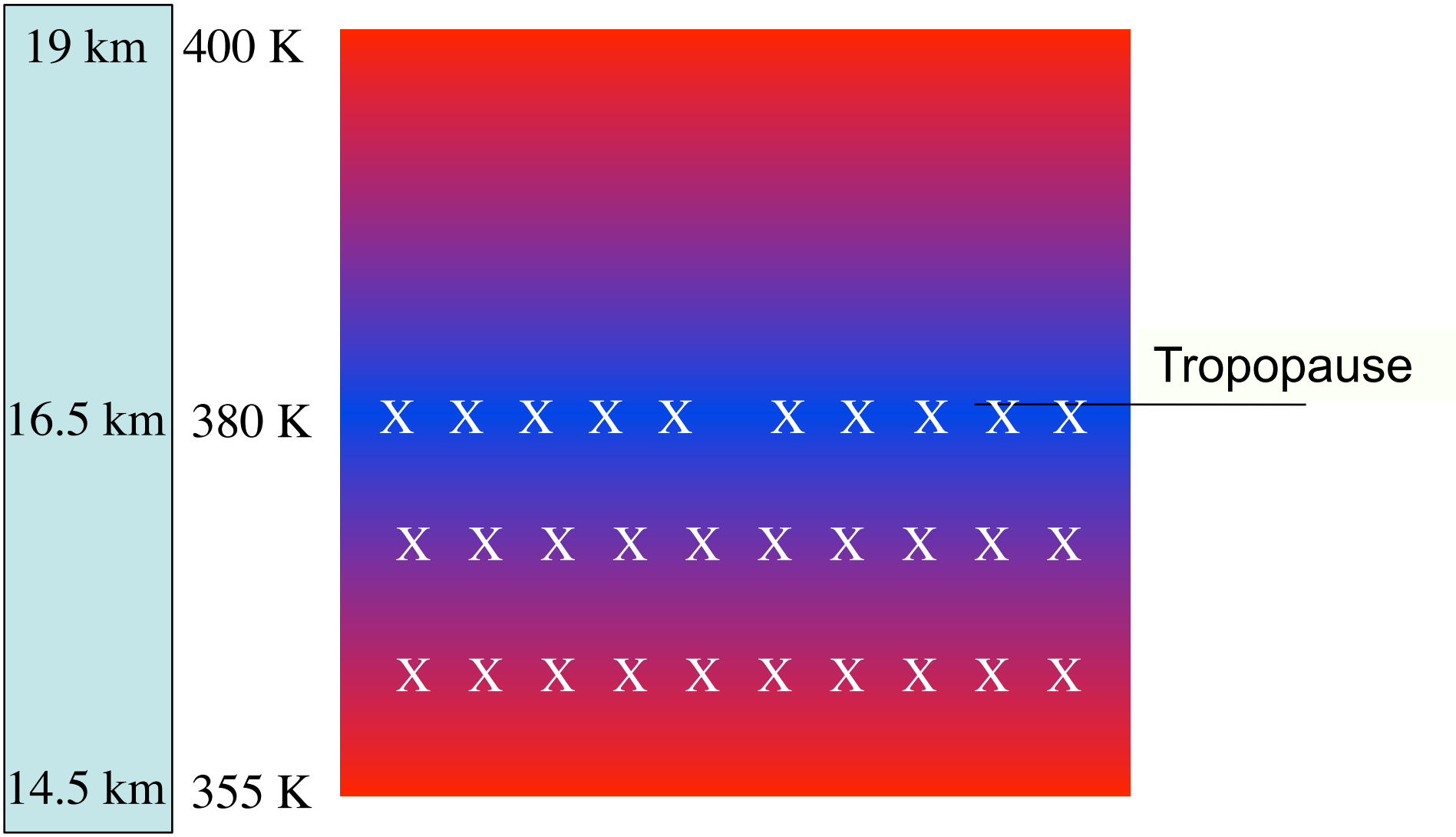

19 km
400 K
16.5 km
380 K
14.5 km
355 K
Tropopause


19 km
400 K
16.5 km
380 K
14.5 km
355 K
Tropopause

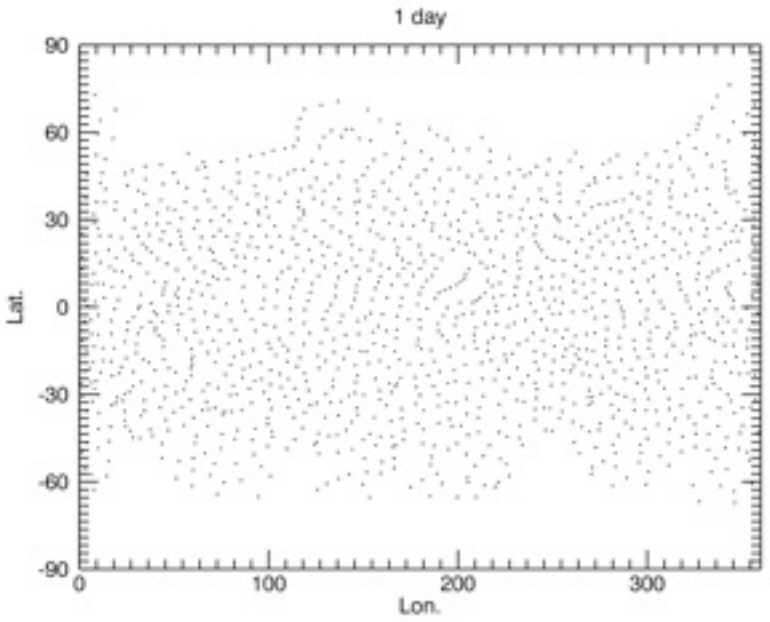

19 km
400 K
16.5 km
380 K
14.5 km
355 K
Tropopause


19 km
400 K
16.5 km
380 K
14.5 km
355 K
Tropopause

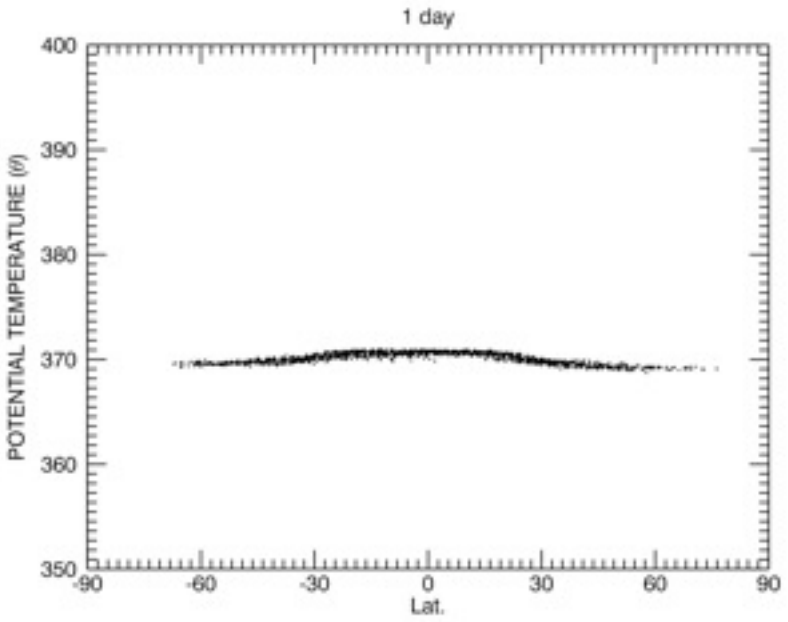

19 km
400 K
16.5 km
380 K
14.5 km
355 K
Tropopause


19 km
400 K
16.5 km
380 K
14.5 km
355 K
Tropopause

1 day

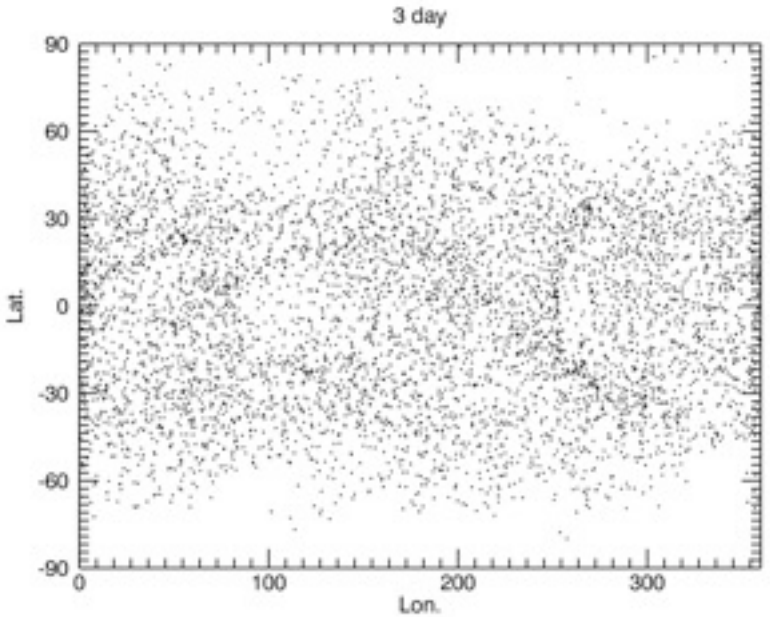


Horizontal view

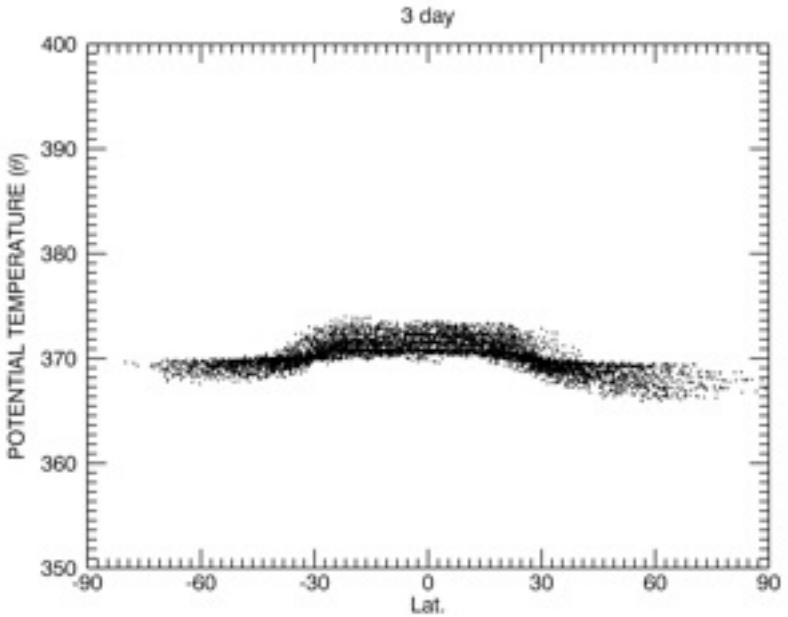


Vertical view

3 days

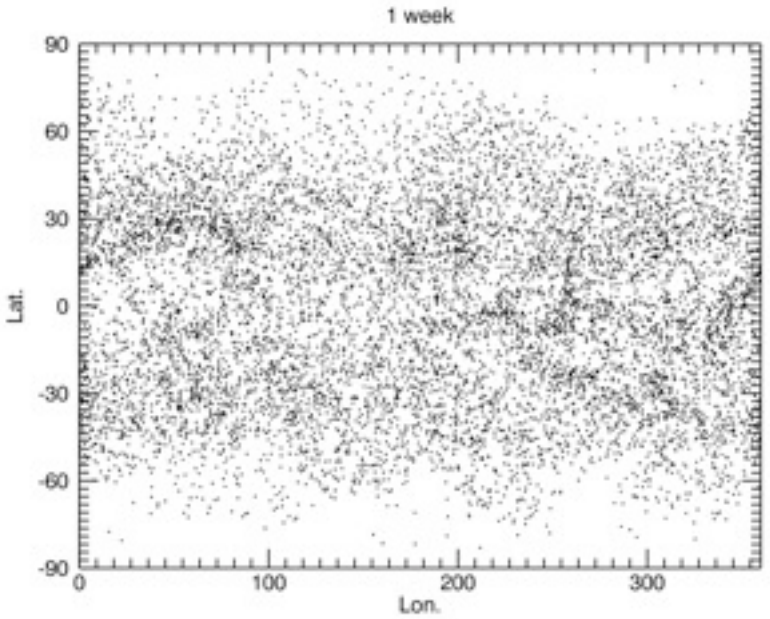


Horizontal view

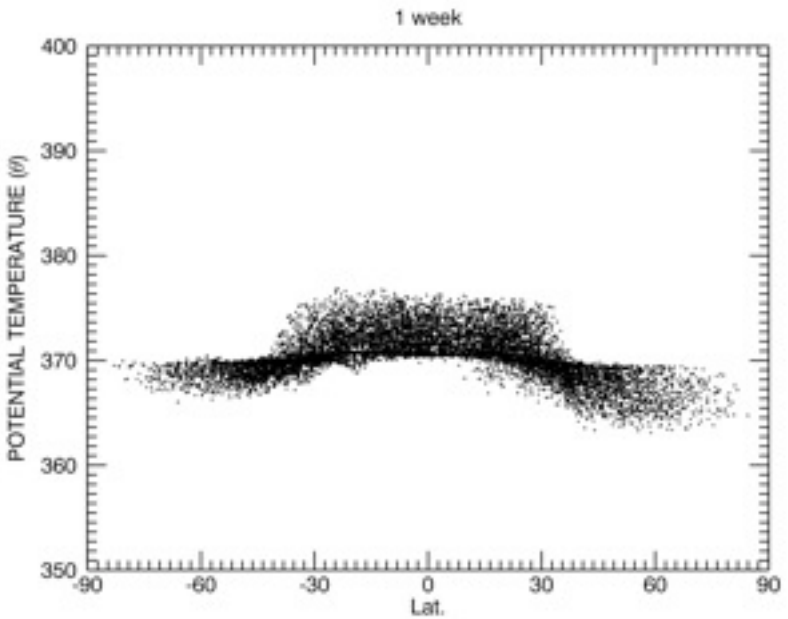


Vertical view

1 week

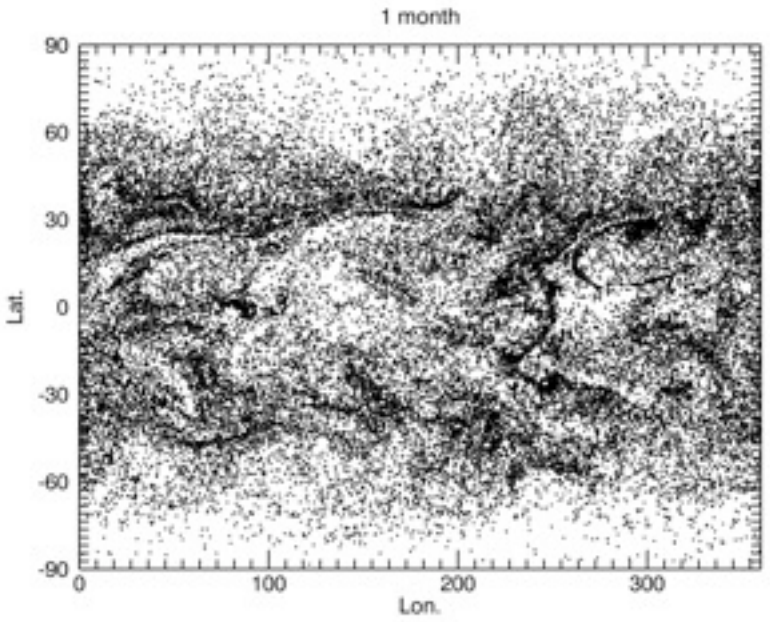


Horizontal view

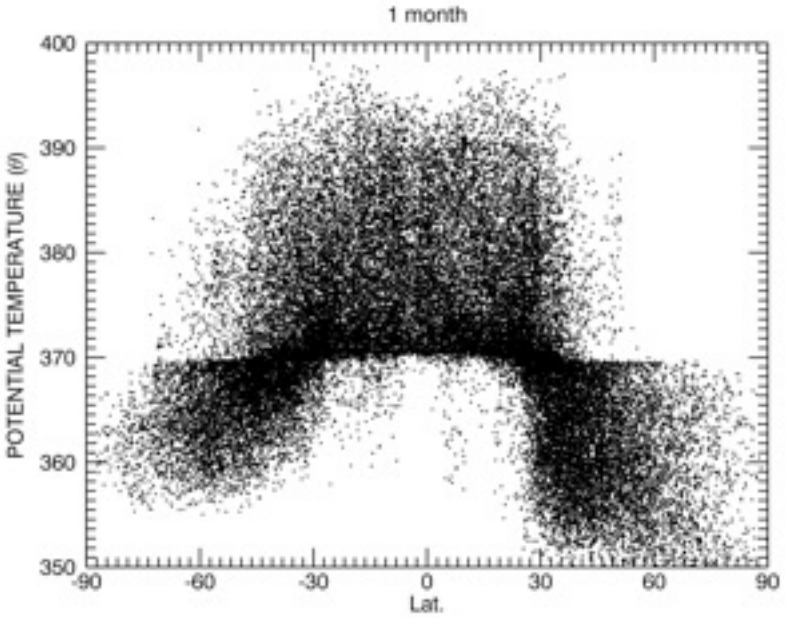


Vertical view

1 month

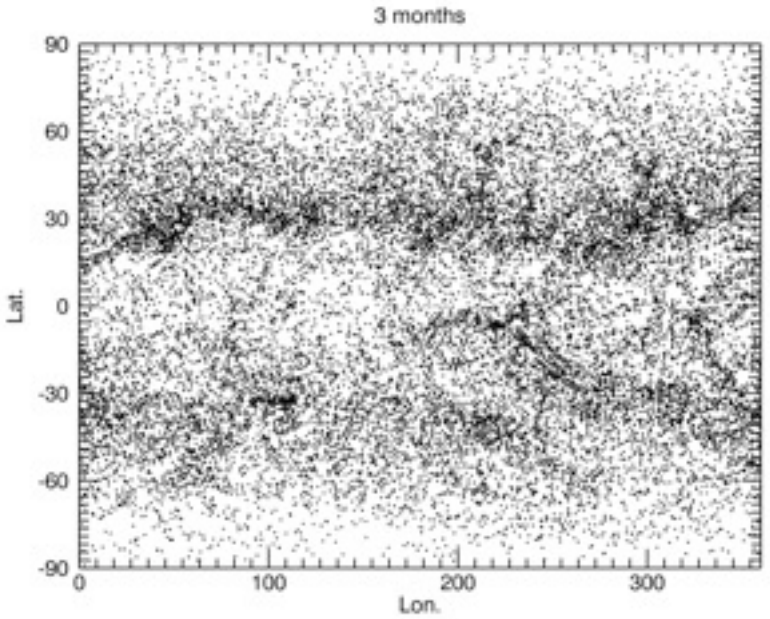


Horizontal view

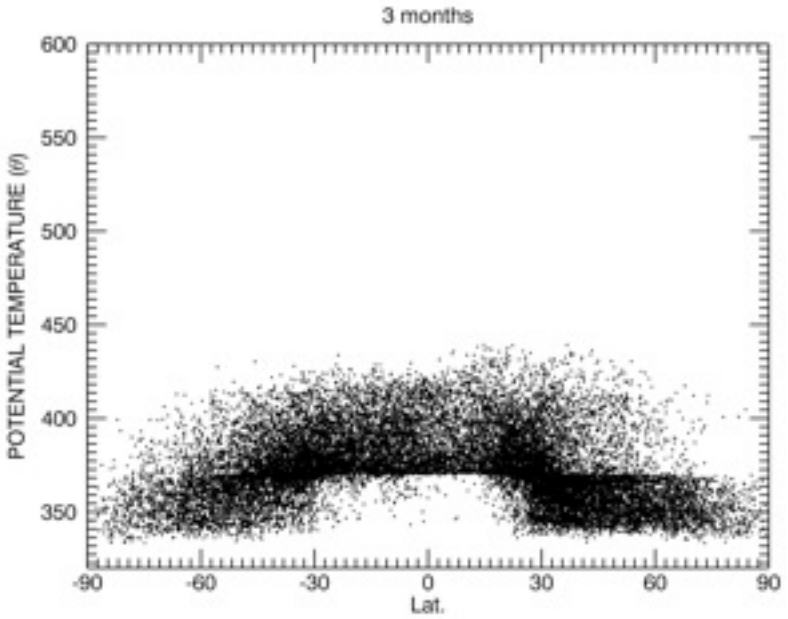


Vertical view

3 months



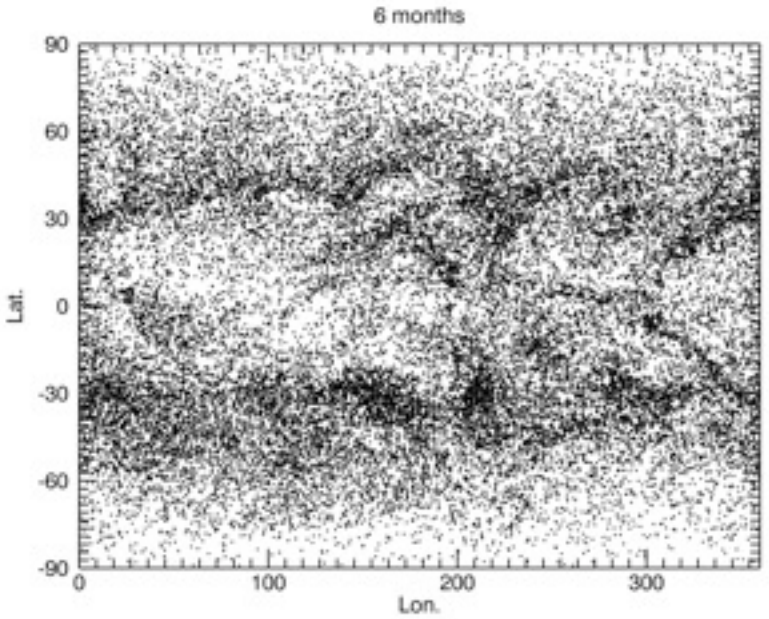
Horizontal view



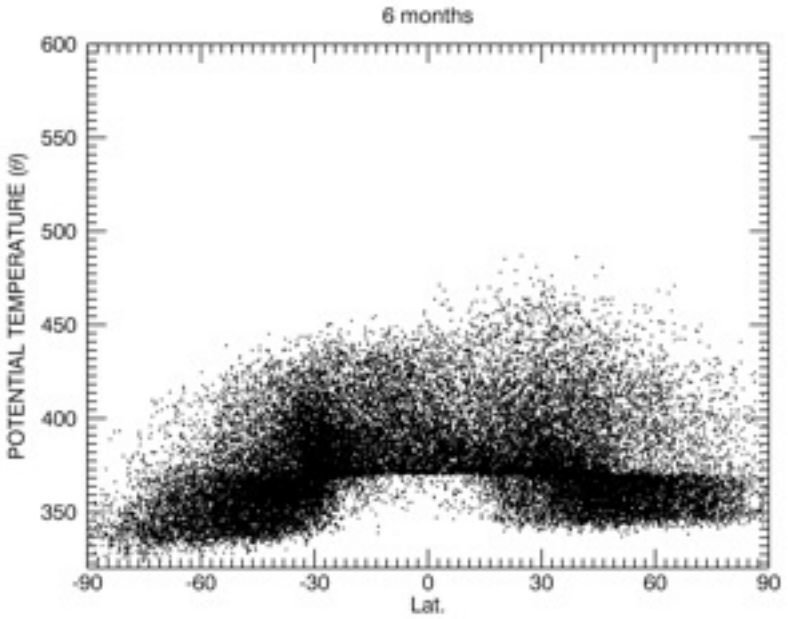
Vertical view

Parcels have been thinned out by a factor of 10
Expanded the altitude scale

6 months



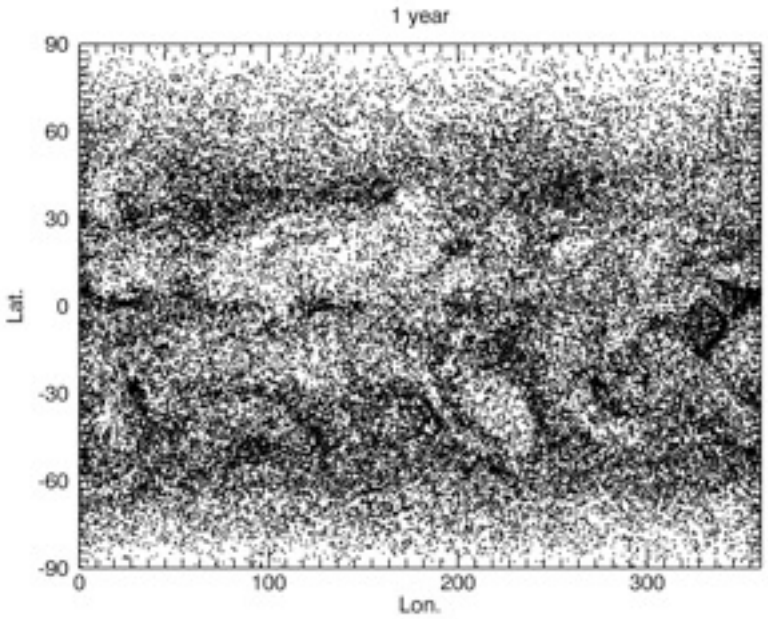
Horizontal view



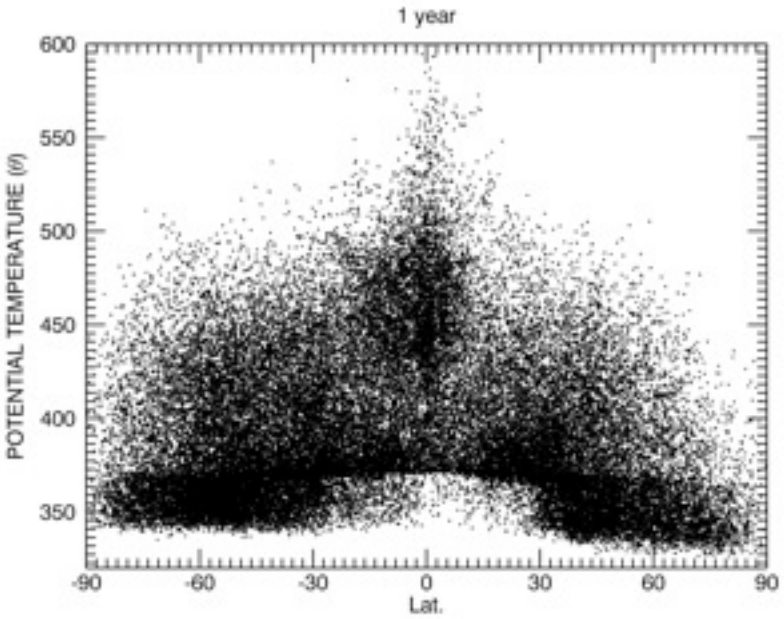
Vertical view

Parcels have been thinned out by a factor of 10

1 year



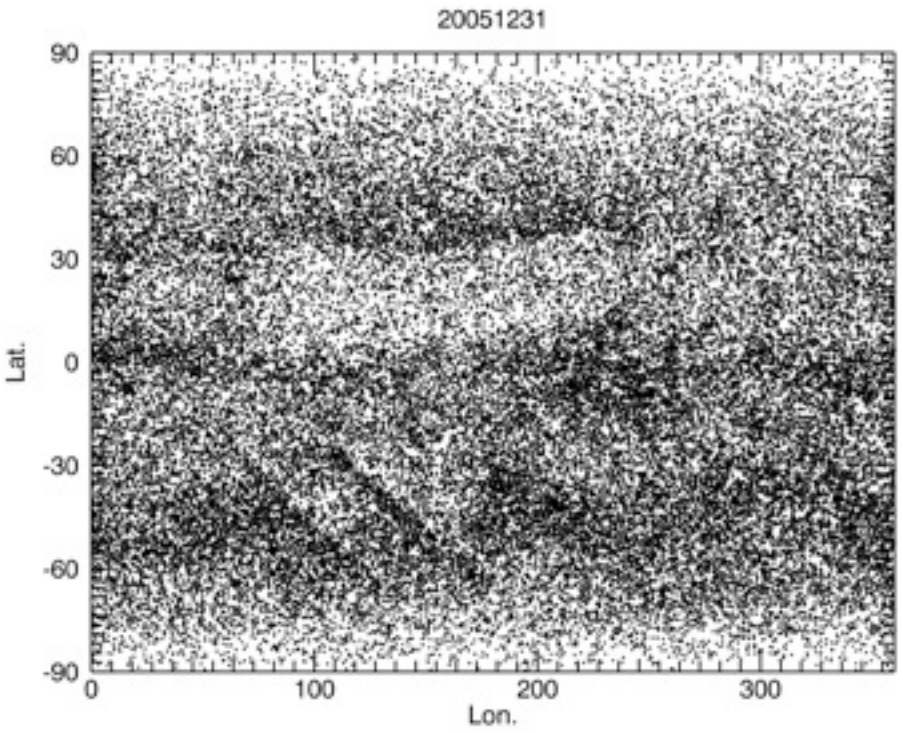
Horizontal view

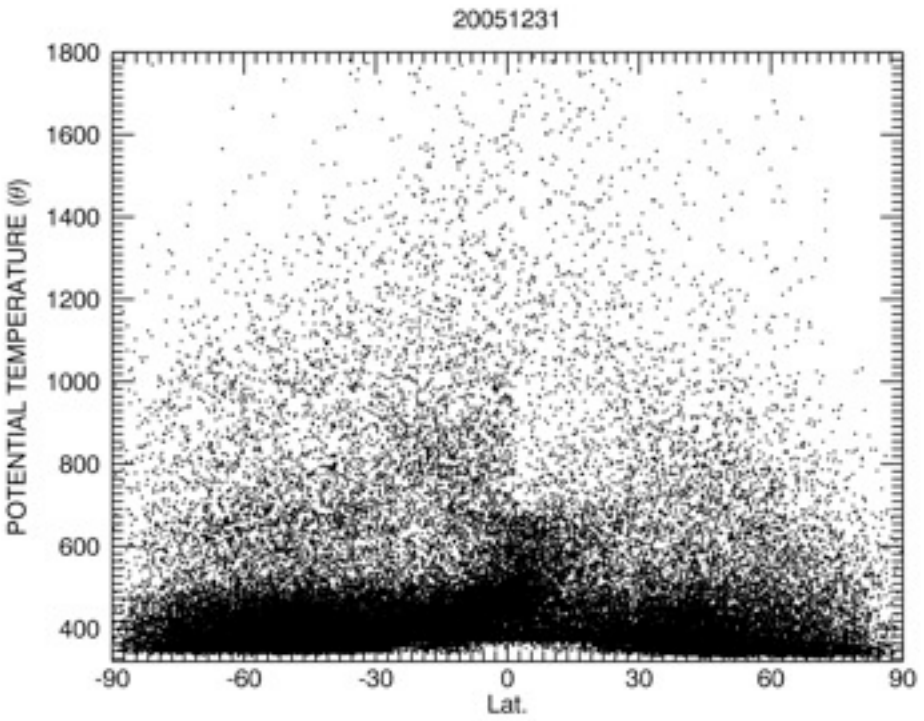


Vertical view

Parcels have been thinned out by a factor of 10

12/31/2005





Horizontal view

Parcels have been thinned out by a factor of 10

Some details

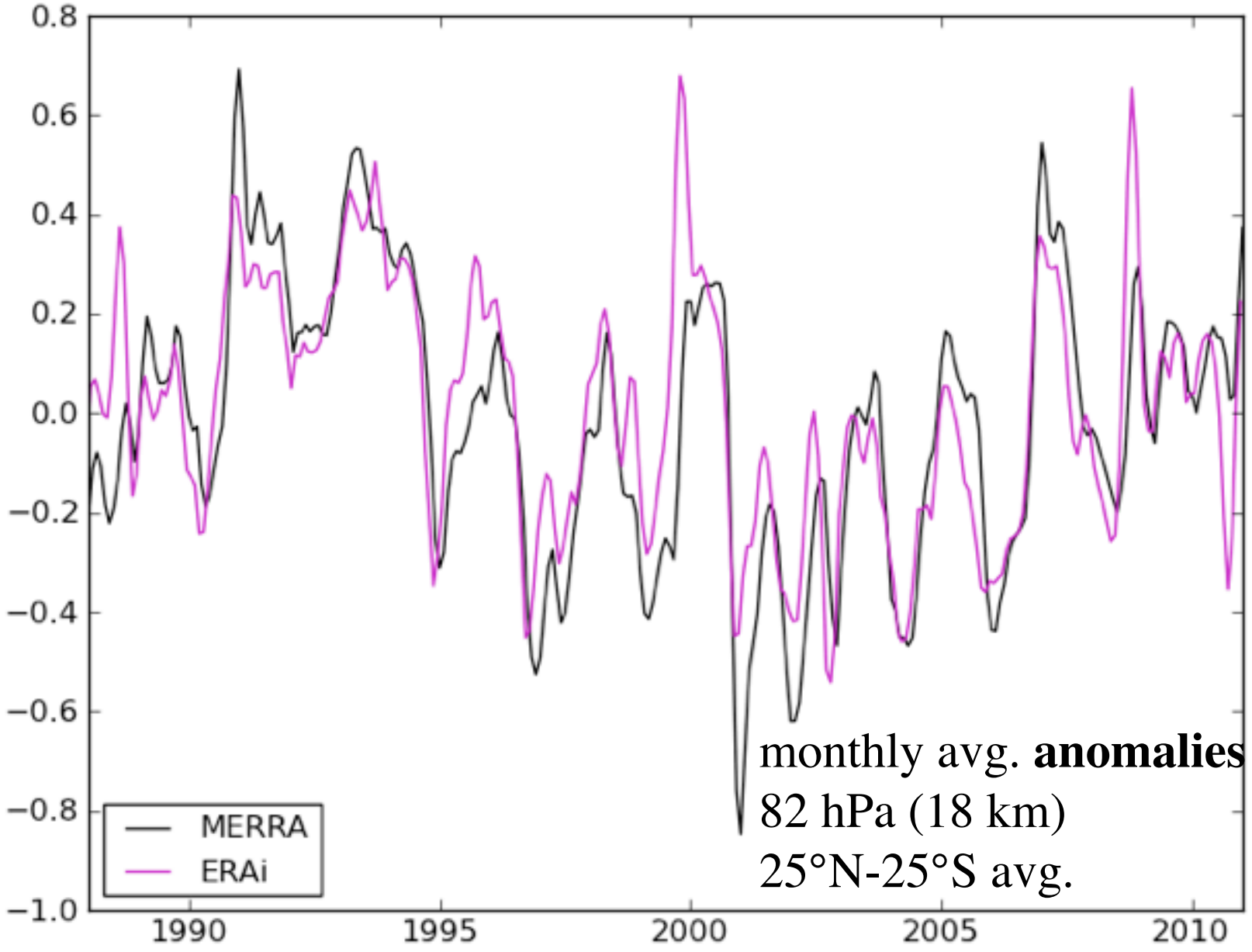
- Bowman trajectory model
- meteorology from MERRA and ERA-interim
- 6-hour instantaneous horizontal winds
- diabatic trajectory 6-hour average heating rates
- add parcels every day @ 365 K
- parcels removed after 10 years or if they descend into the troposphere
- Model has CH_4 oxidation

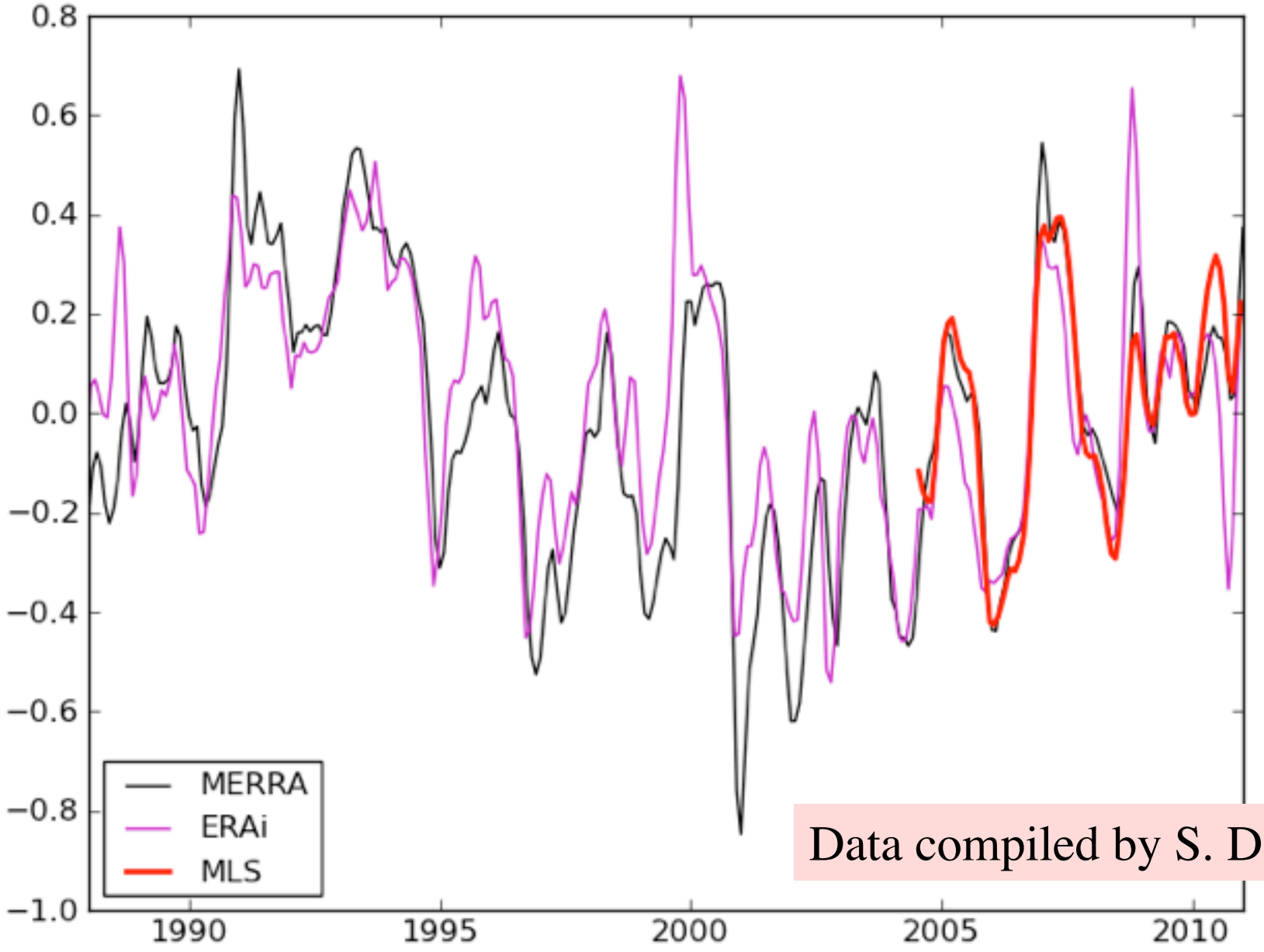
Some details

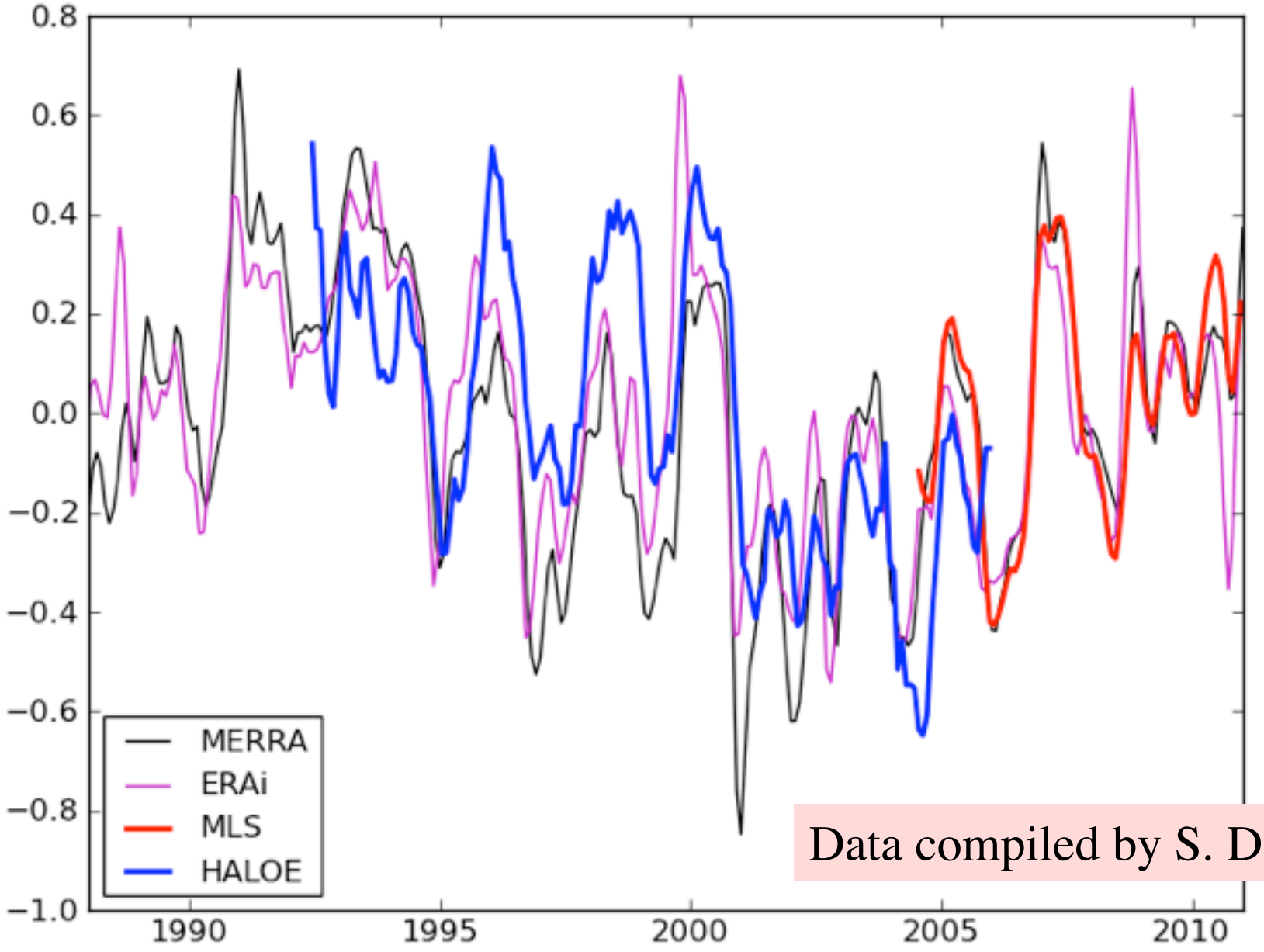
- Bowman trajectory model
- meteorology from MERRA and ERA-interim
- 6-hour instantaneous horizontal winds
- diabatic trajectory 6-hour average heating

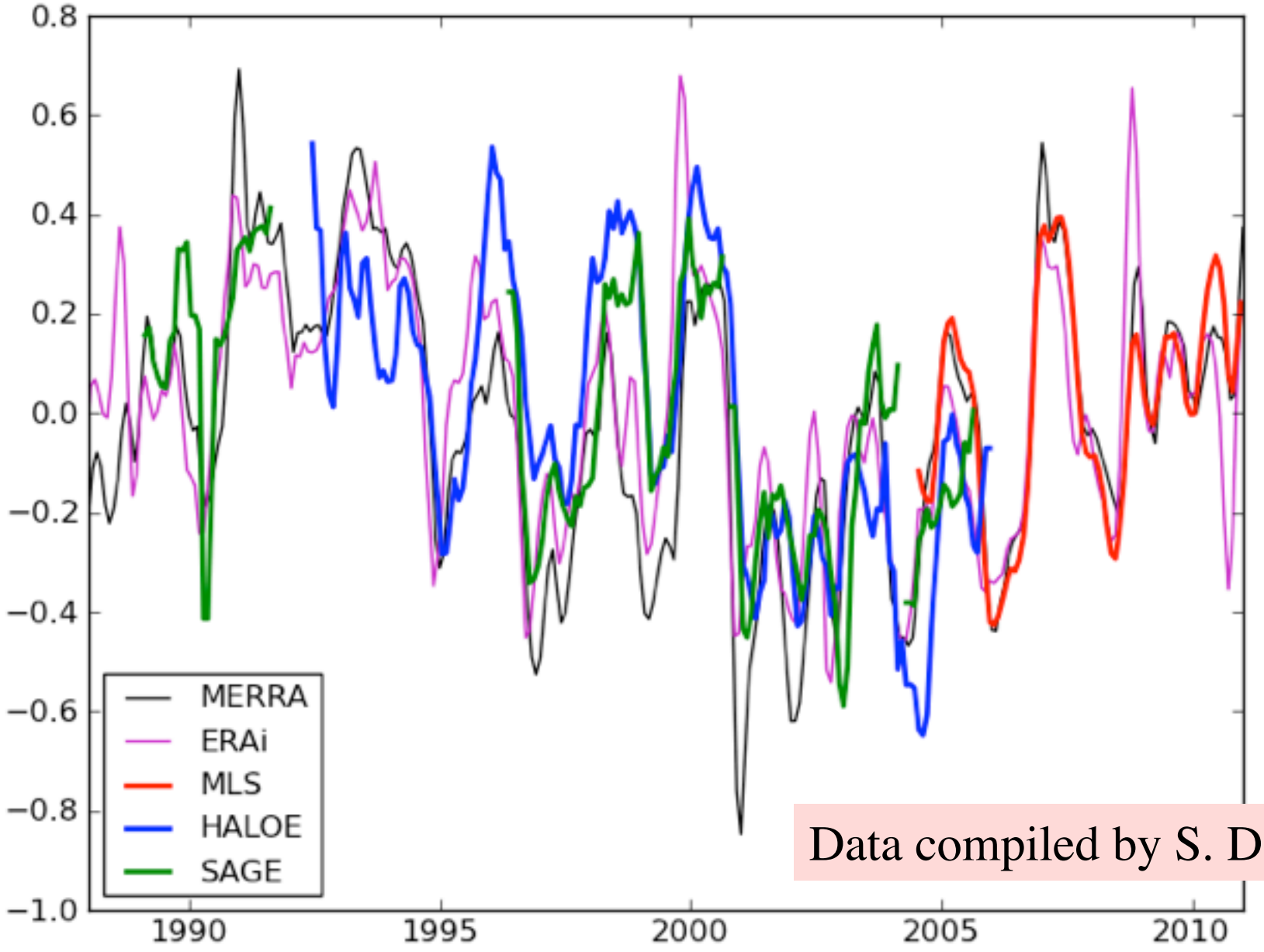
Schoeberl, M. R., and A. E. Dessler, Dehydration of the stratosphere, Atmos. Chem. Phys., 11, doi: 10.5194/acp-11-8433-2011, 8433-8446

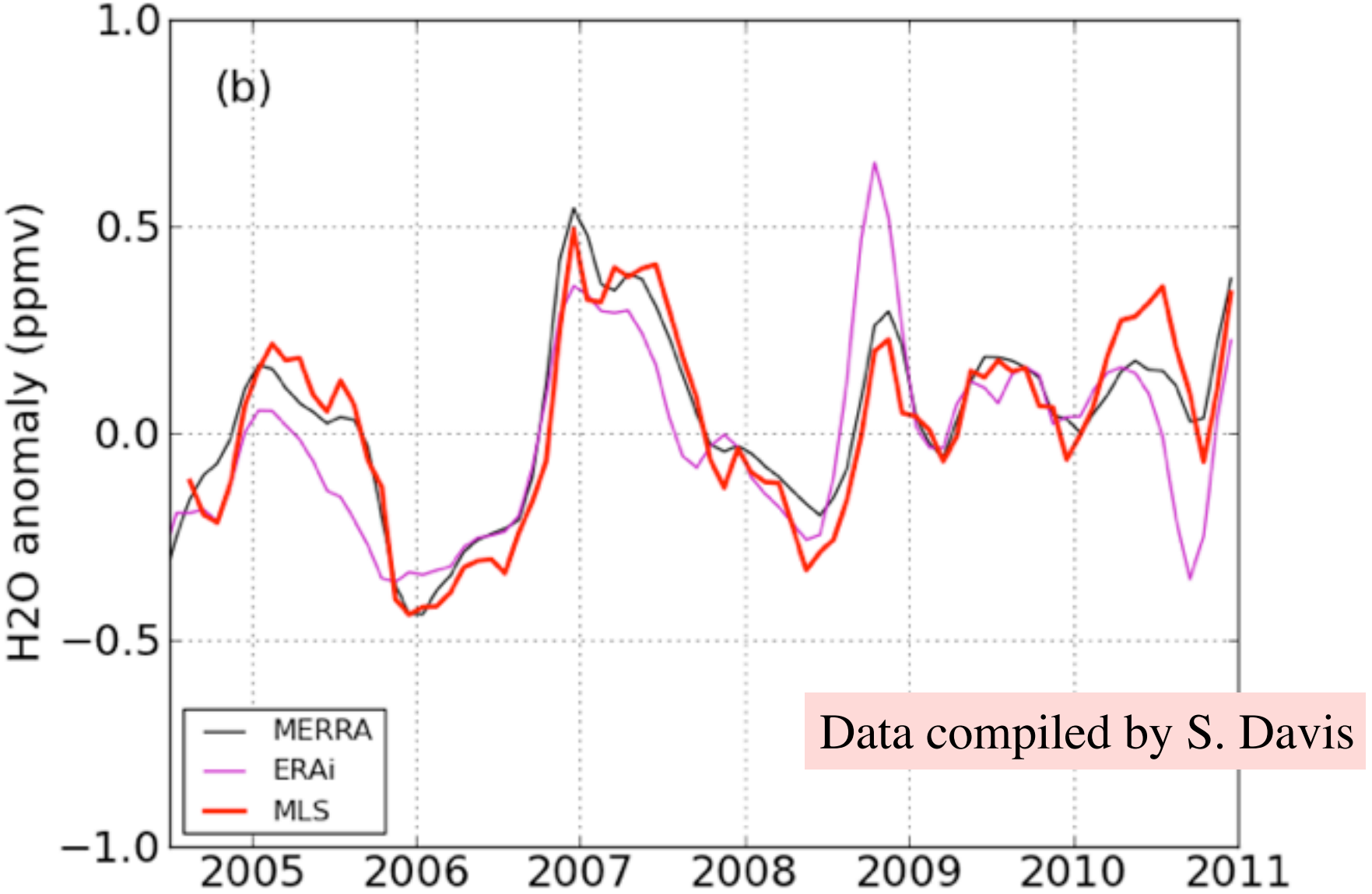
Schoeberl, M. R., A. E. Dessler, and T. Wang, 2012: Simulation of stratospheric water vapor and trends using three reanalyses, Atmos. Chem. Phys., 12, doi:10.5194/acp-12-6475-2012, 6475-6487.


0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
1990
1995
2000
2005
2010
MERRA
ERAi
monthly avg. **anomalies**
82 hPa (18 km)
25°N-25°S avg.

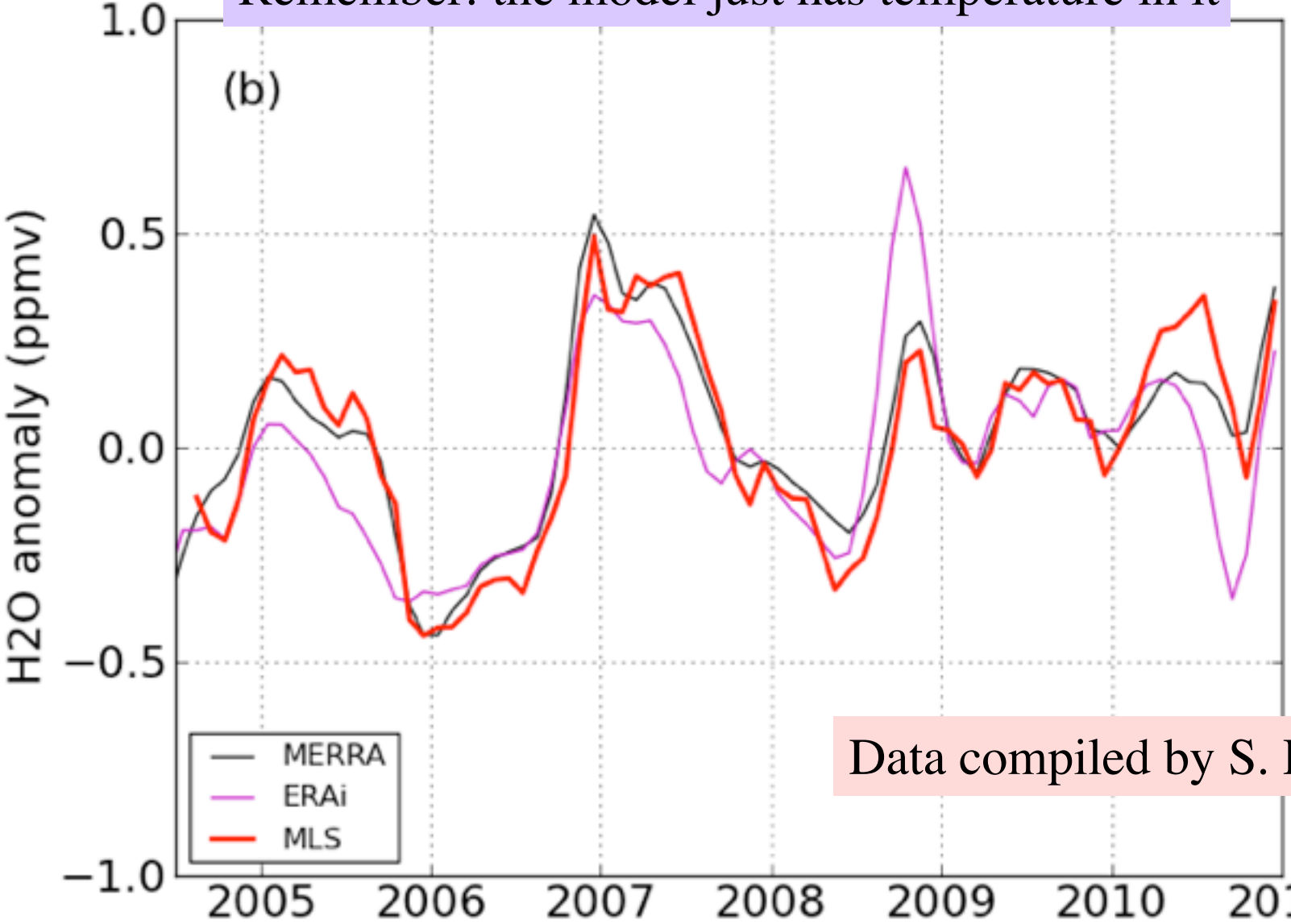

0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
1990
1995
2000
2005
2010
MERRA
ERAi
MLS
Data compiled by S. Davis


0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
1990
1995
2000
2005
2010
MERRA
ERAi
MLS
HALOE
Data compiled by S. Davis


0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
1990
1995
2000
2005
2010
MERRA
ERAi
MLS
HALOE
SAGE
Data compiled by S. Davis

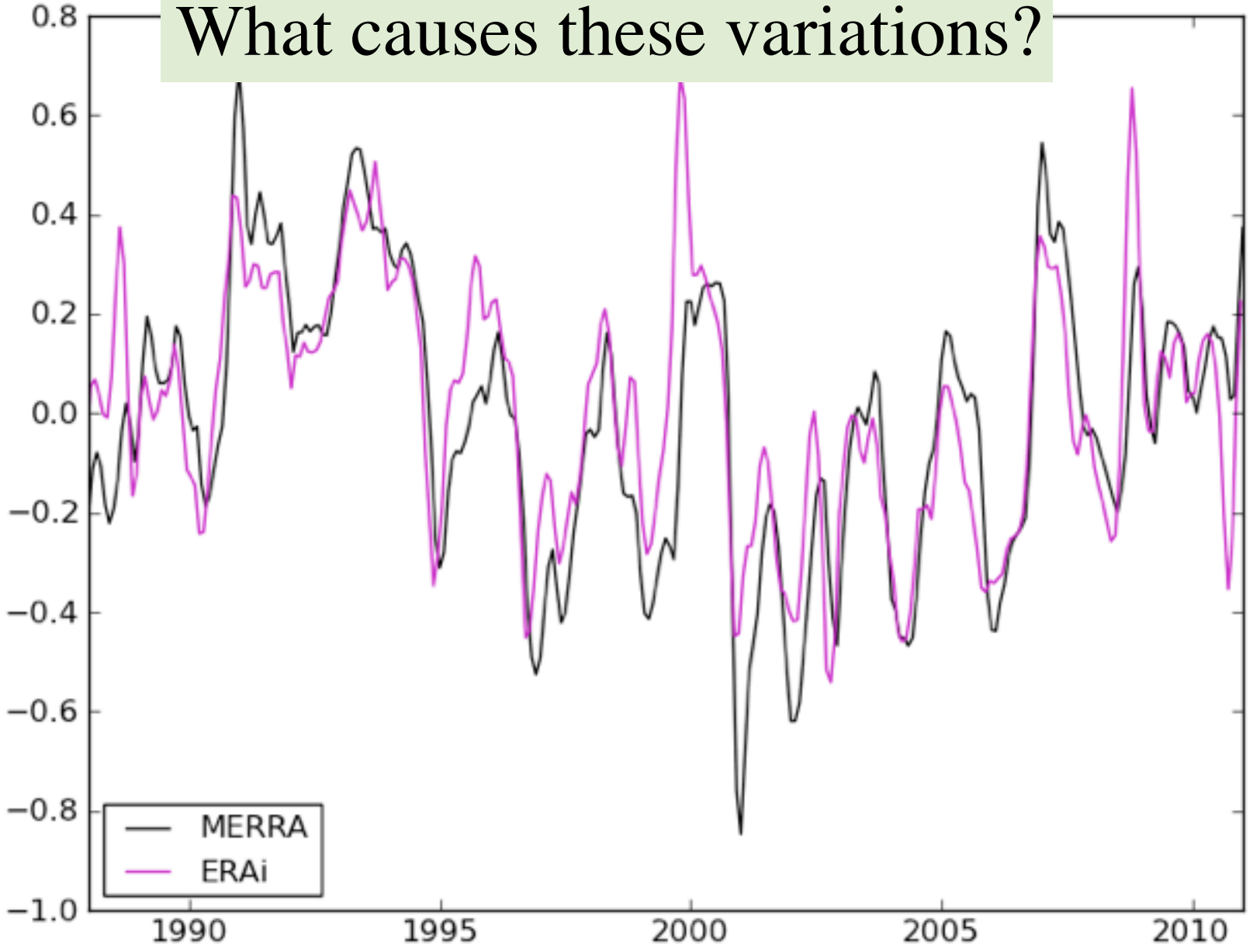

(b)
H2O anomaly (ppmv)
1.0
0.5
0.0
−0.5
−1.0
2005
2006
2007
2008
2009
2010
2011
MERRA
ERAi
MLS
Data compiled by S. Davis

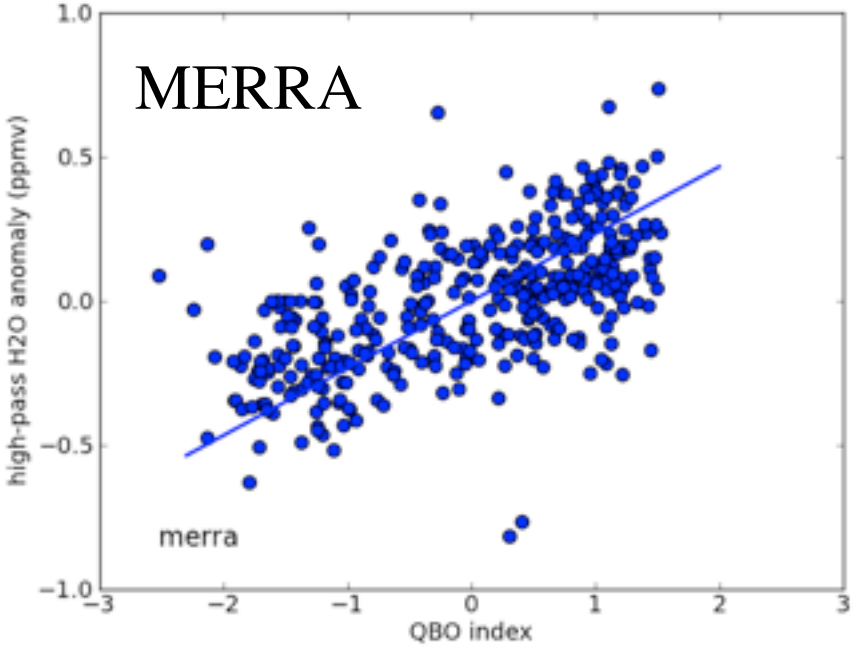
Remember: the model just has temperature in it

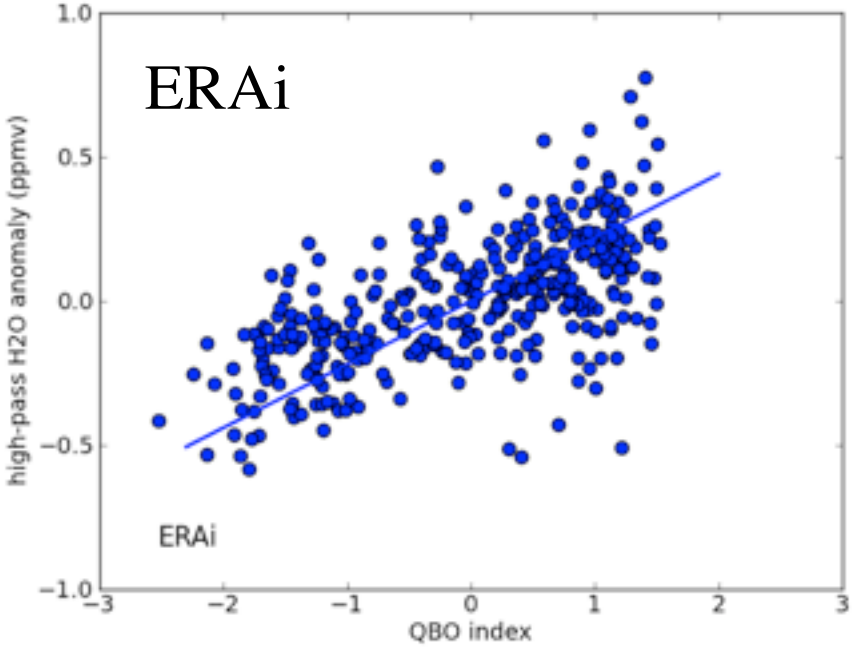


Data compiled by S. Davis

What causes these variations?

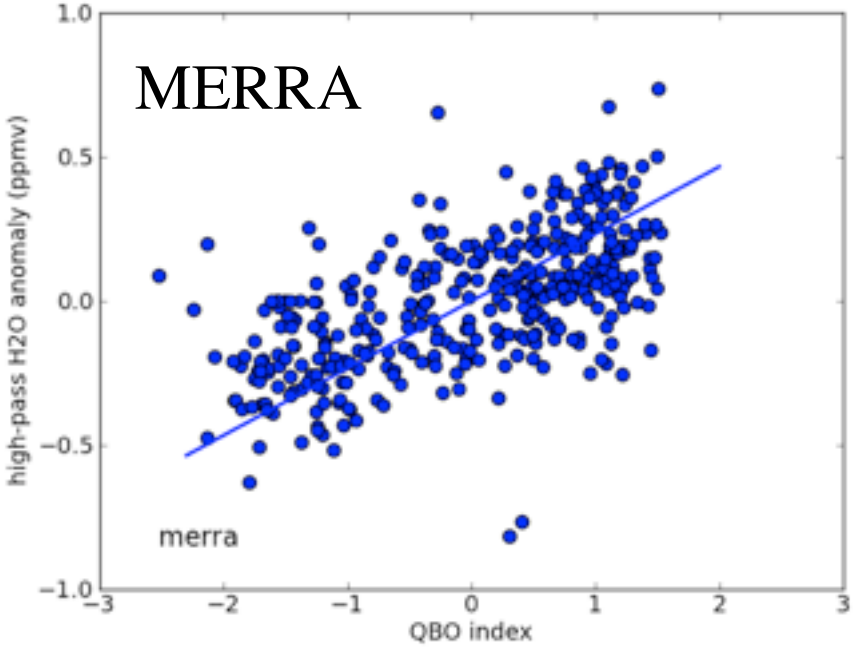


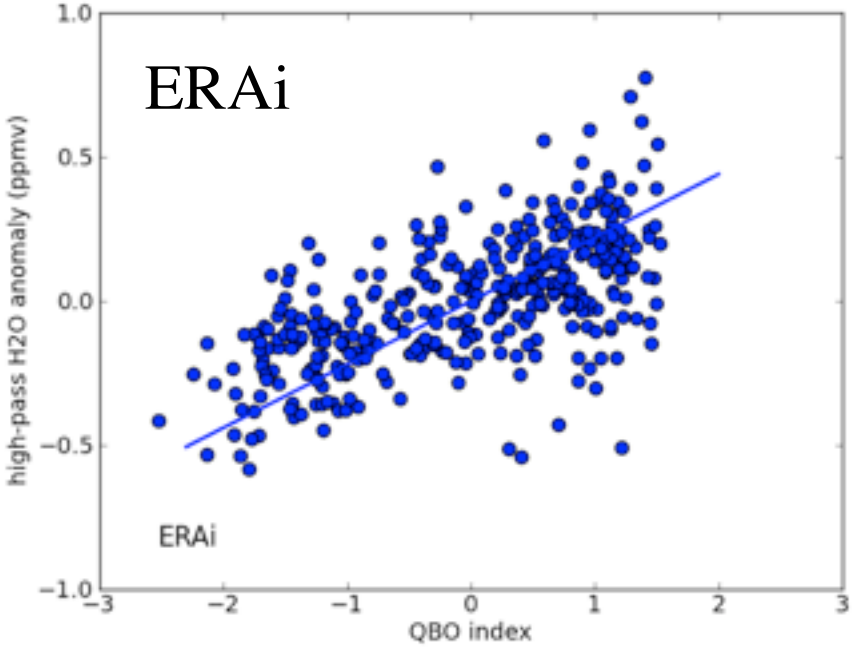




slope = 0.23 ppmv

slope = 0.22 ppmv





slope = 0.23 ppmv

slope = 0.22 ppmv

peak-to-peak amplitude
of the QBO = ~0.45 ppmv

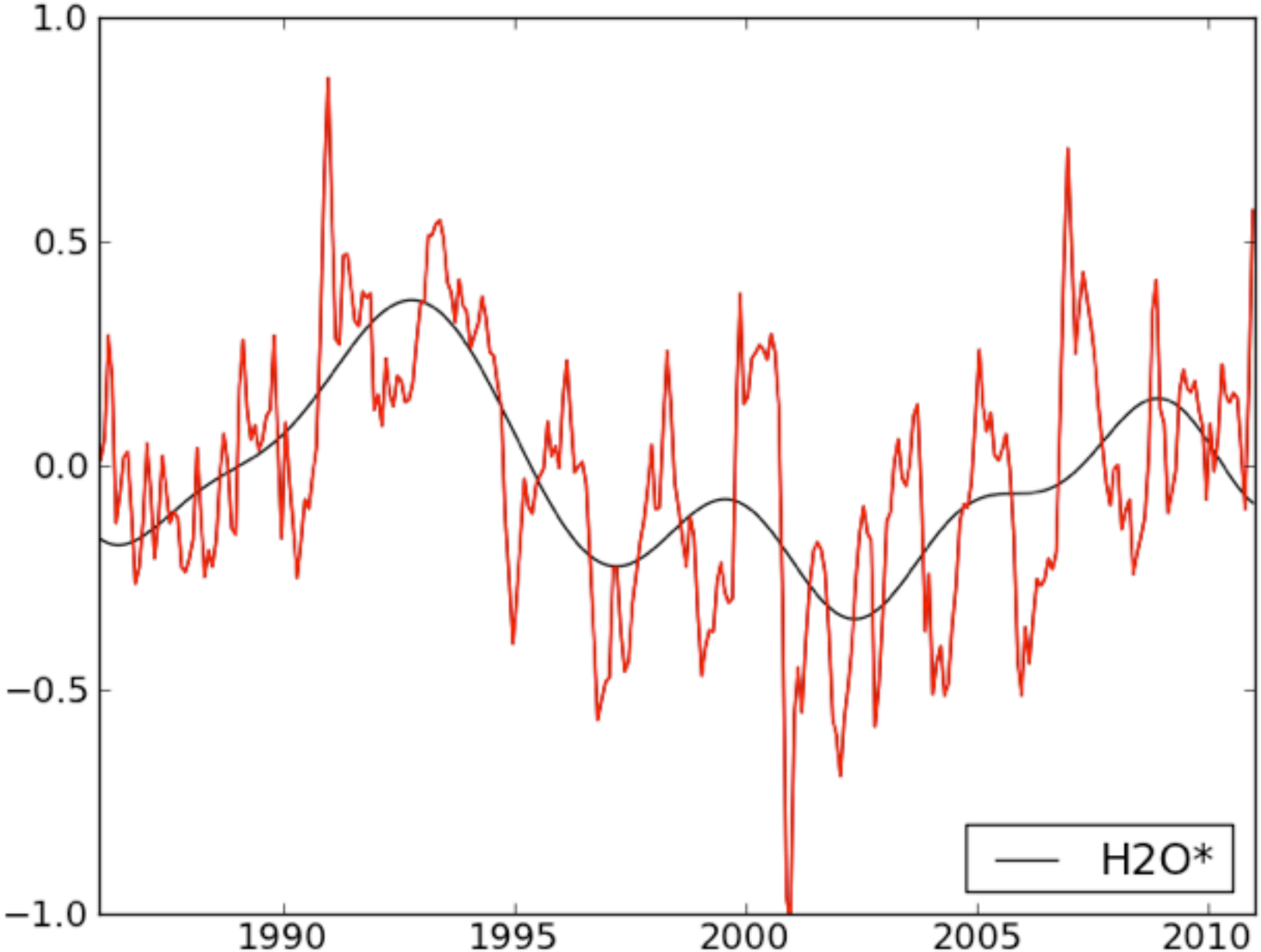
[consistent with Giorgetta and Bengtsson, 1999;
Geller et al., 2002; Randel et al., 2004;
Chiou et al., 2006]

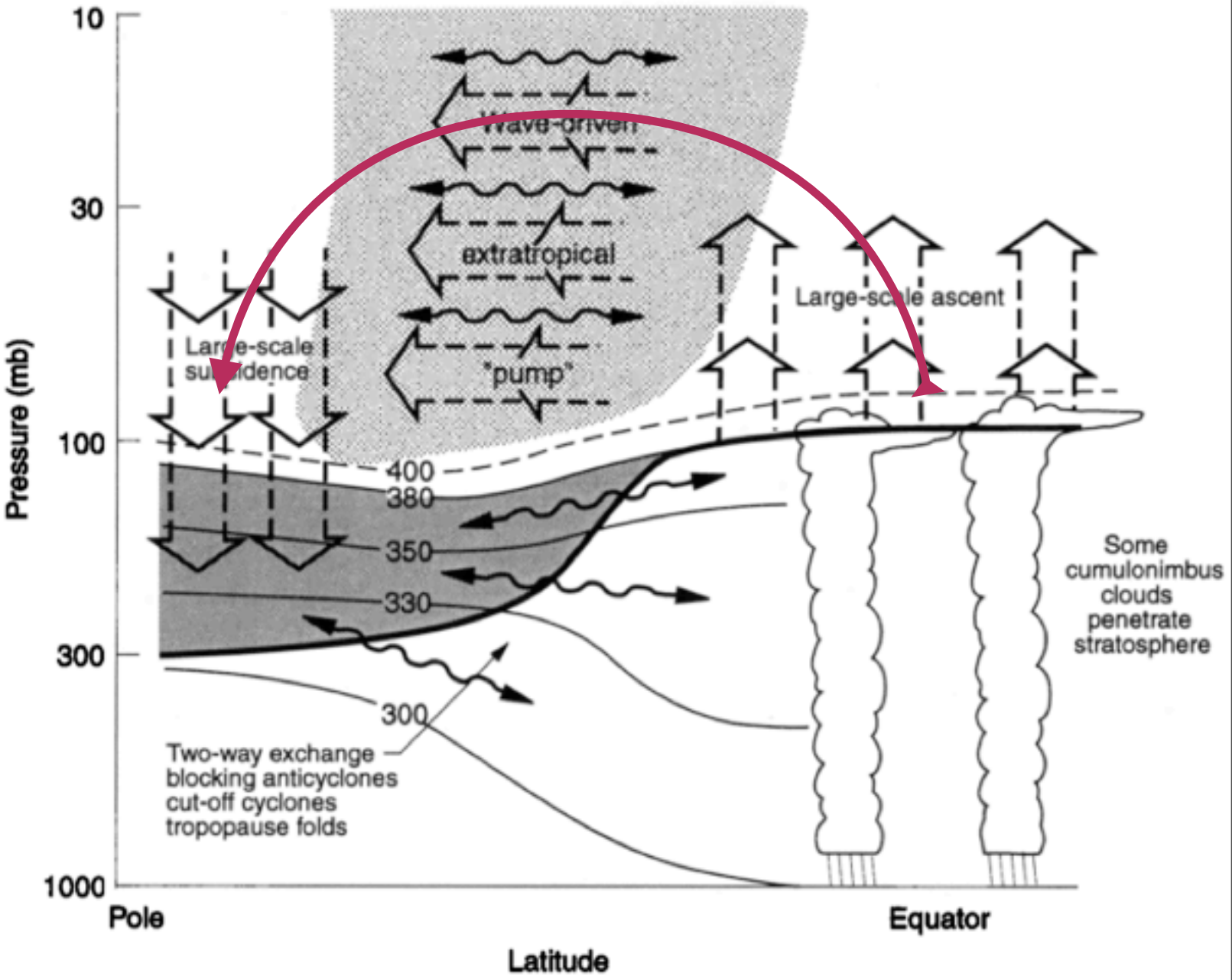
What controls interannual variability of stratospheric water?

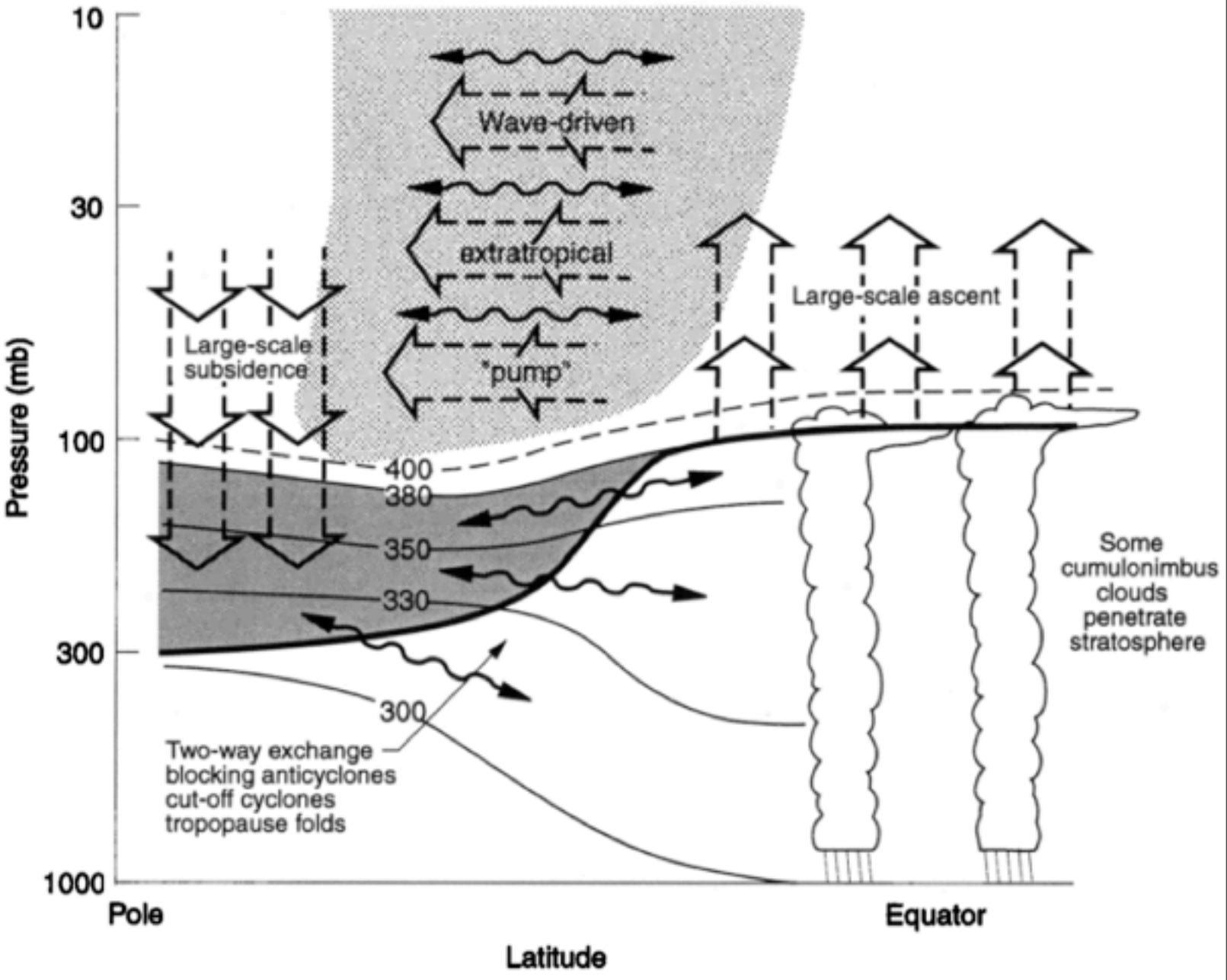
QBO	0.45 ppmv

What controls interannual variability of stratospheric water?

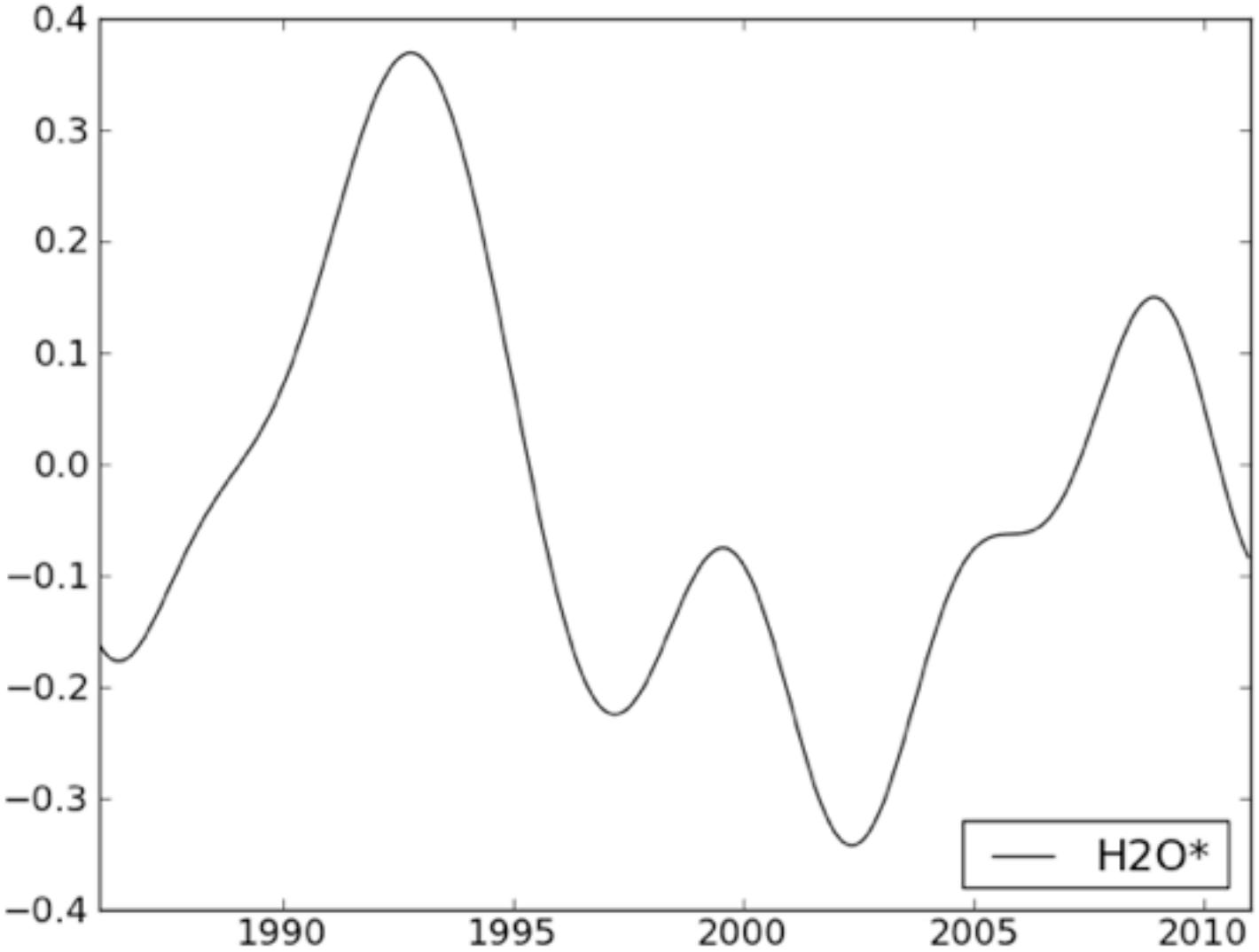
QBO	0.45 ppmv
ENSO	~ zero


1.0
0.5
0.0
−0.5
−1.0
1990
1995
2000
2005
2010
H2O*

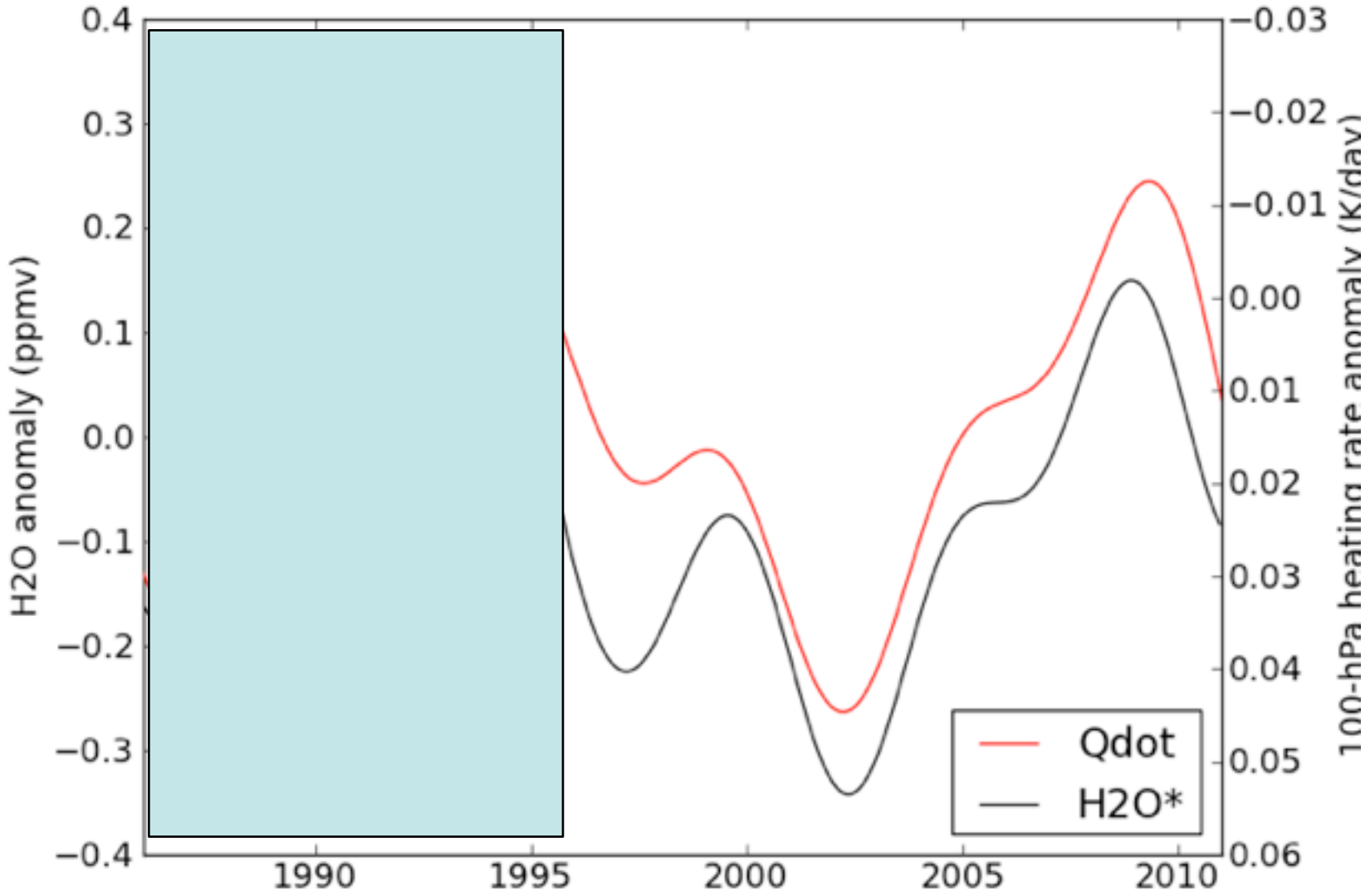

10
30
100
300
1000
Pressure (mb)
Wave-driven
extratropical
"pump"
Large-scale ascent
Large-scale subsidence
400
380
350
330
300
Some cumulonimbus clouds penetrate stratosphere
Two-way exchange
blocking anticyclones
cut-off cyclones
tropopause folds
Pole
Equator
Latitude


10
30
100
300
1000
Pressure (mb)
Wave-driven
extratropical
"pump"
Large-scale
subsidence
Large-scale ascent
400
380
350
330
300
Some
cumulonimbus
clouds
penetrate
stratosphere
Two-way exchange
blocking anticyclones
cut-off cyclones
tropopause folds
Pole
Equator
Latitude

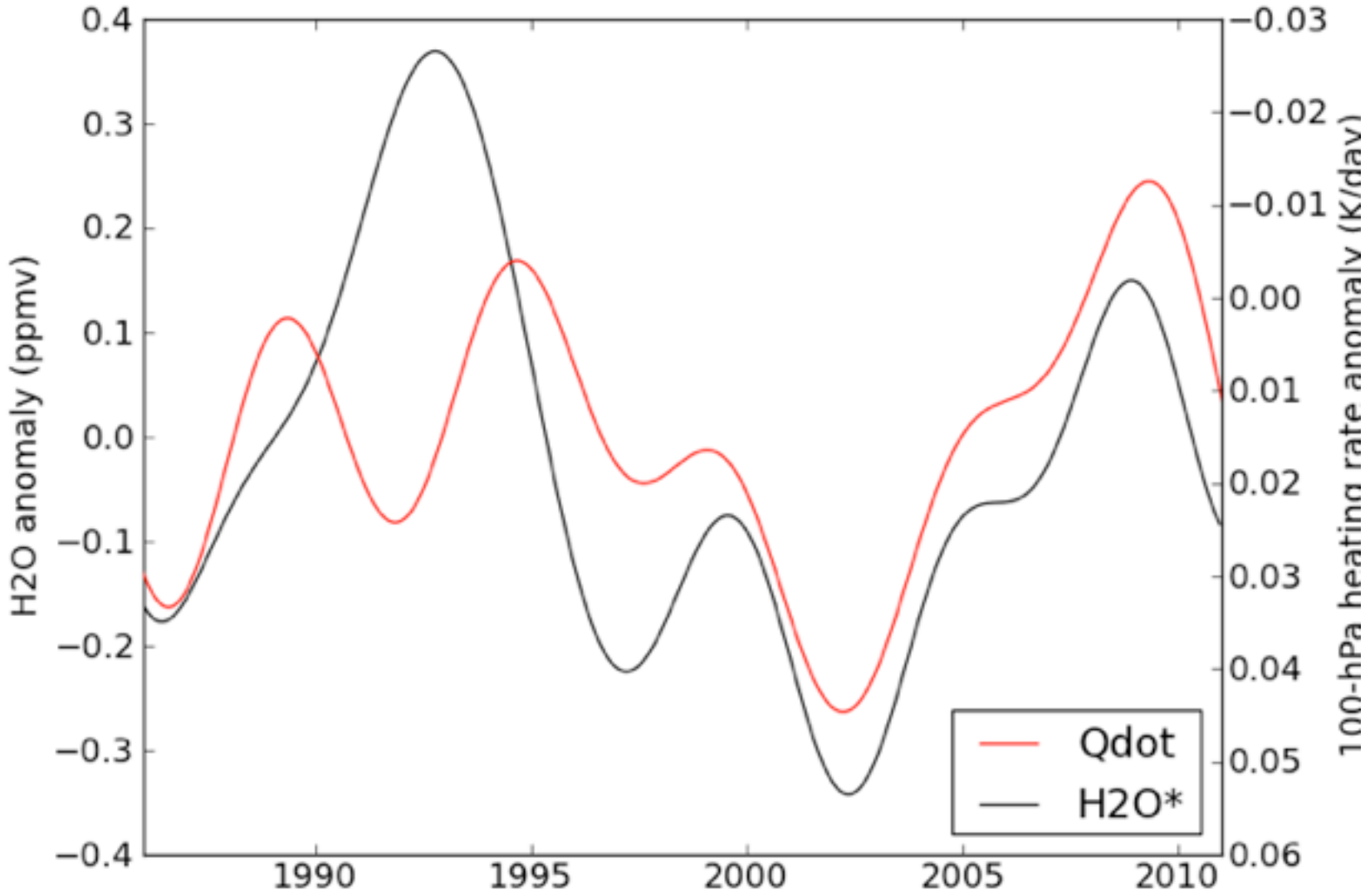
smoothed MERRA H2O* with low-pass (5-year) filter

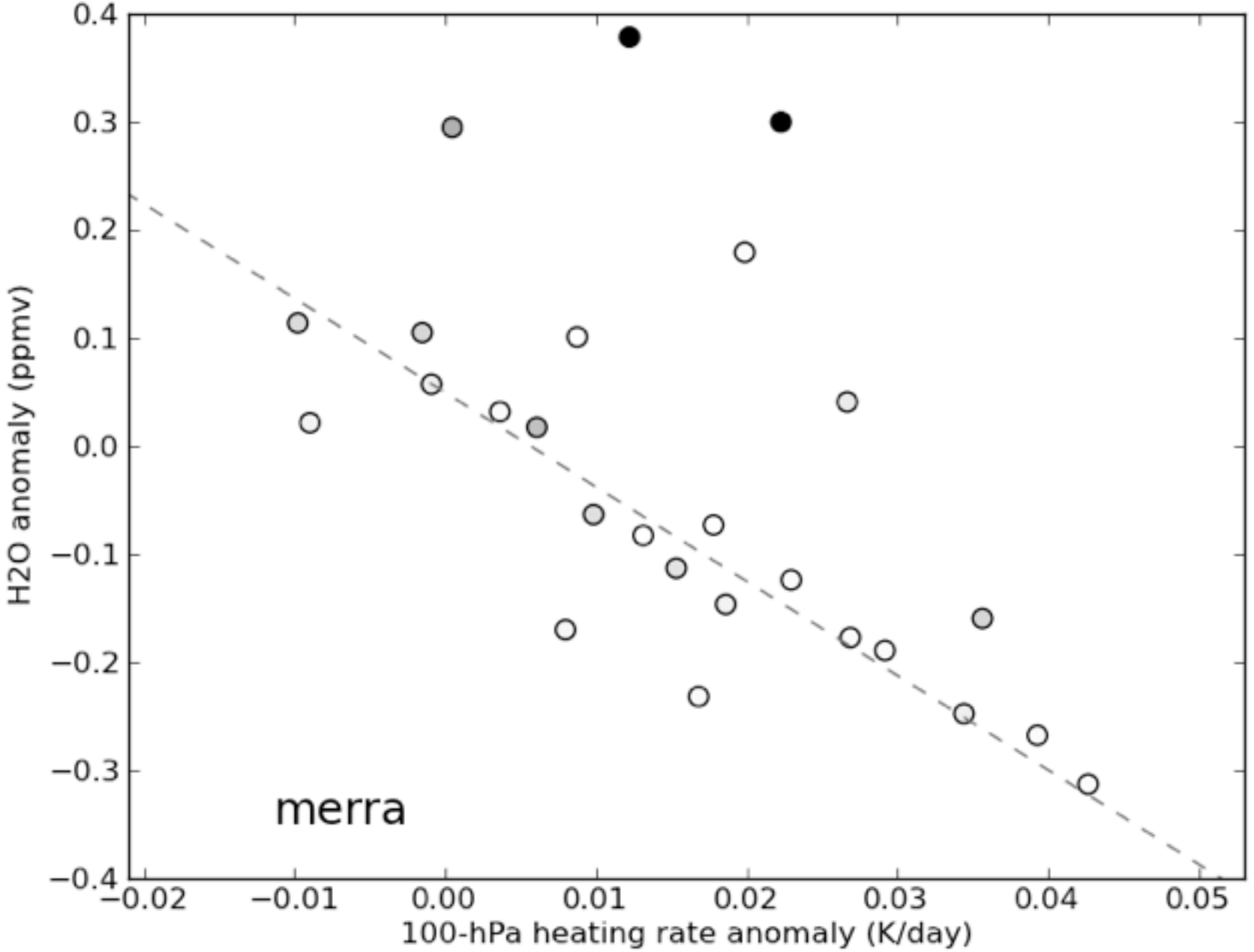


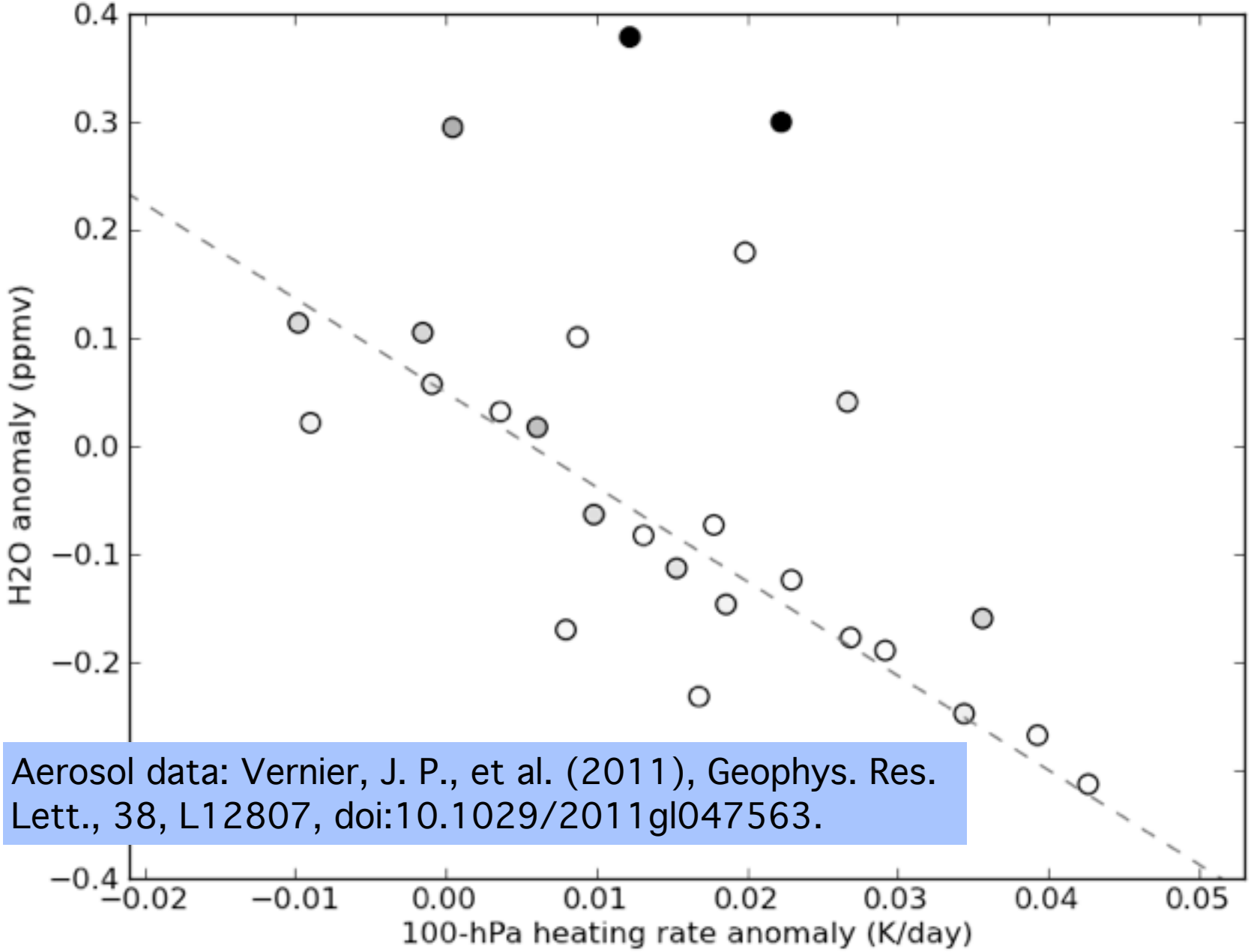
Qdot = 100-hPa heating rate averaged 25N-25S
smoothed with 5-year FFT filter



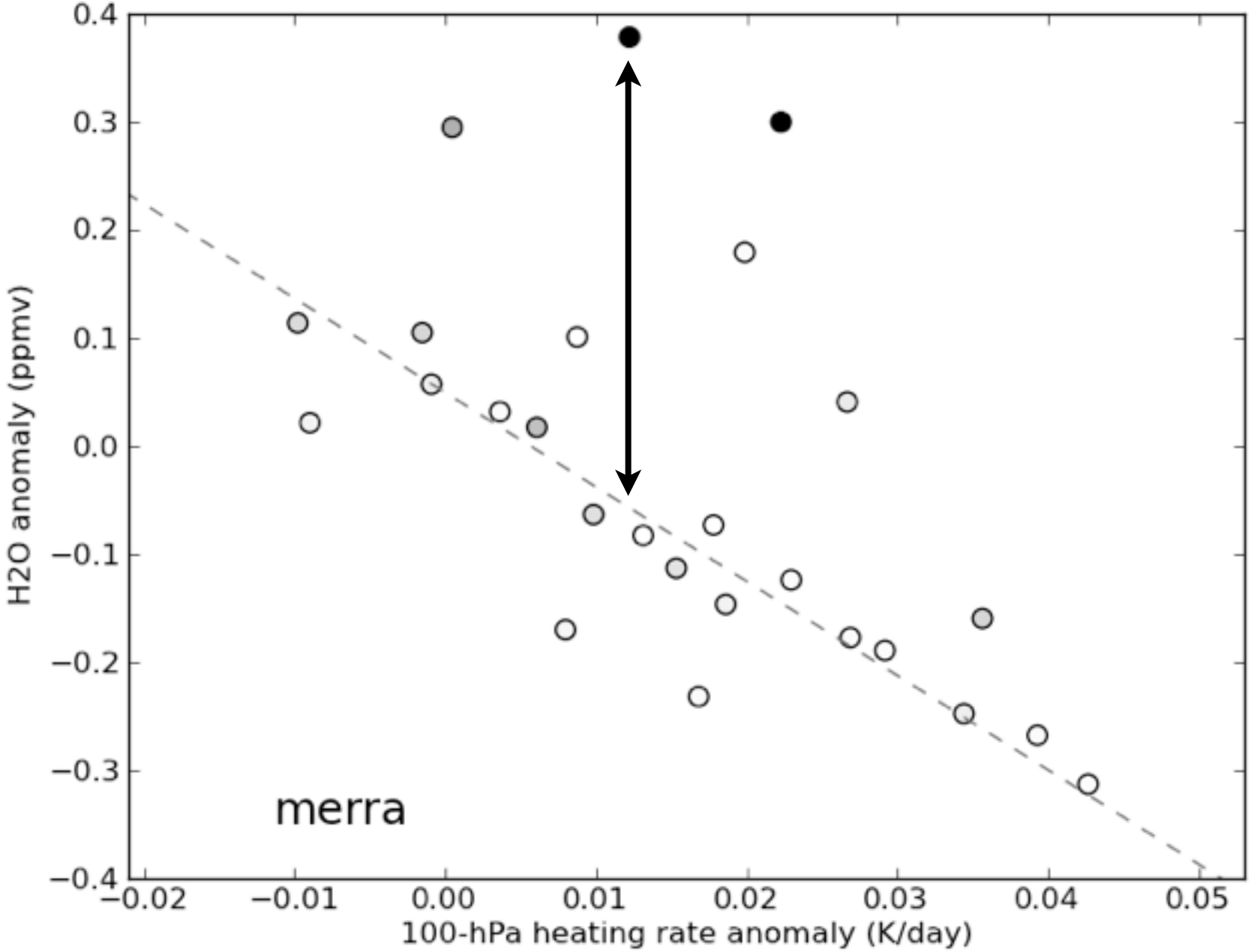
Qdot = 100-hPa heating rate averaged 25N-25S
smoothed with 5-year FFT filter

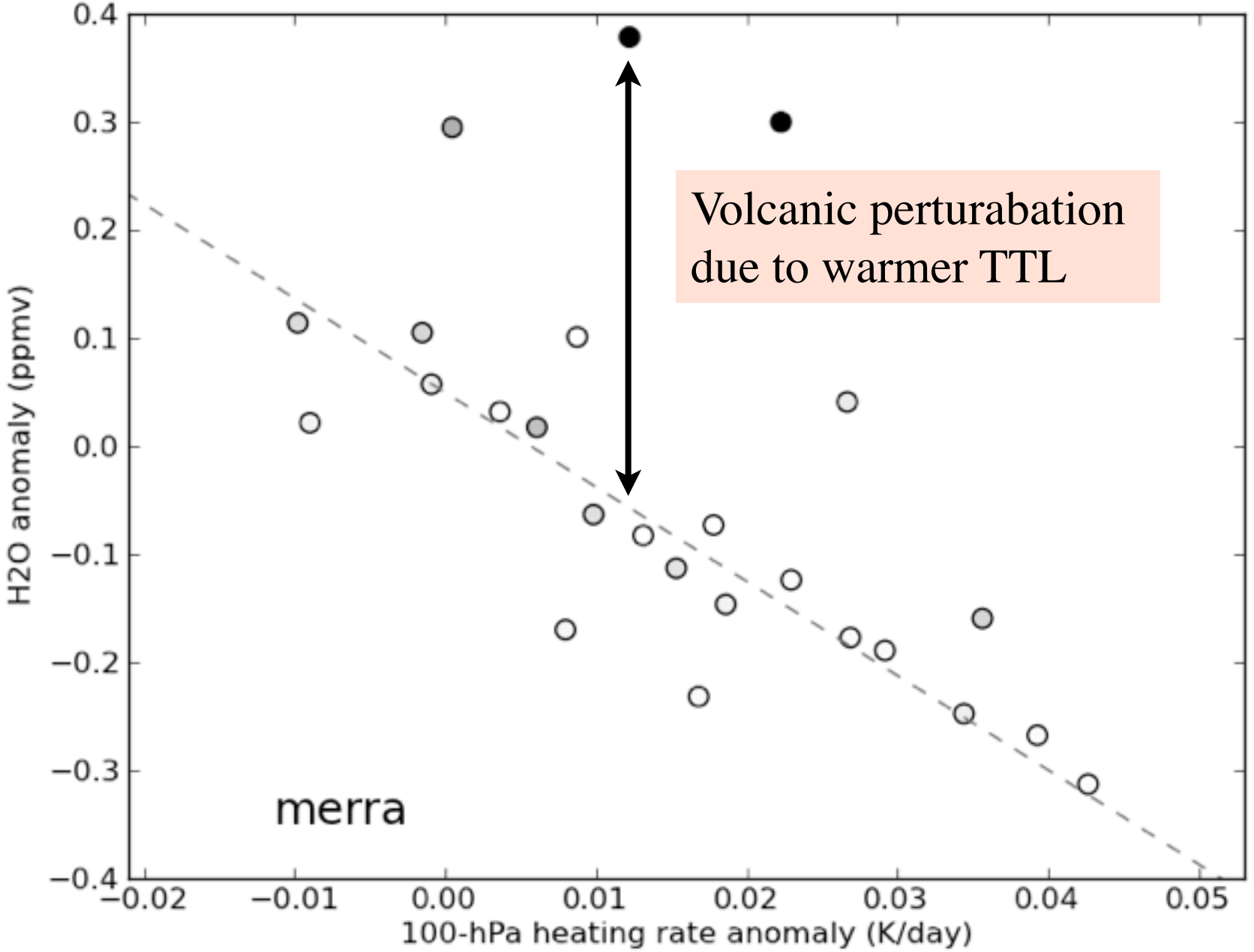



0.4
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
−0.4
H2O anomaly (ppmv)
−0.02
−0.01
0.00
0.01
0.02
0.03
0.04
0.05
100-hPa heating rate anomaly (K/day)
merra



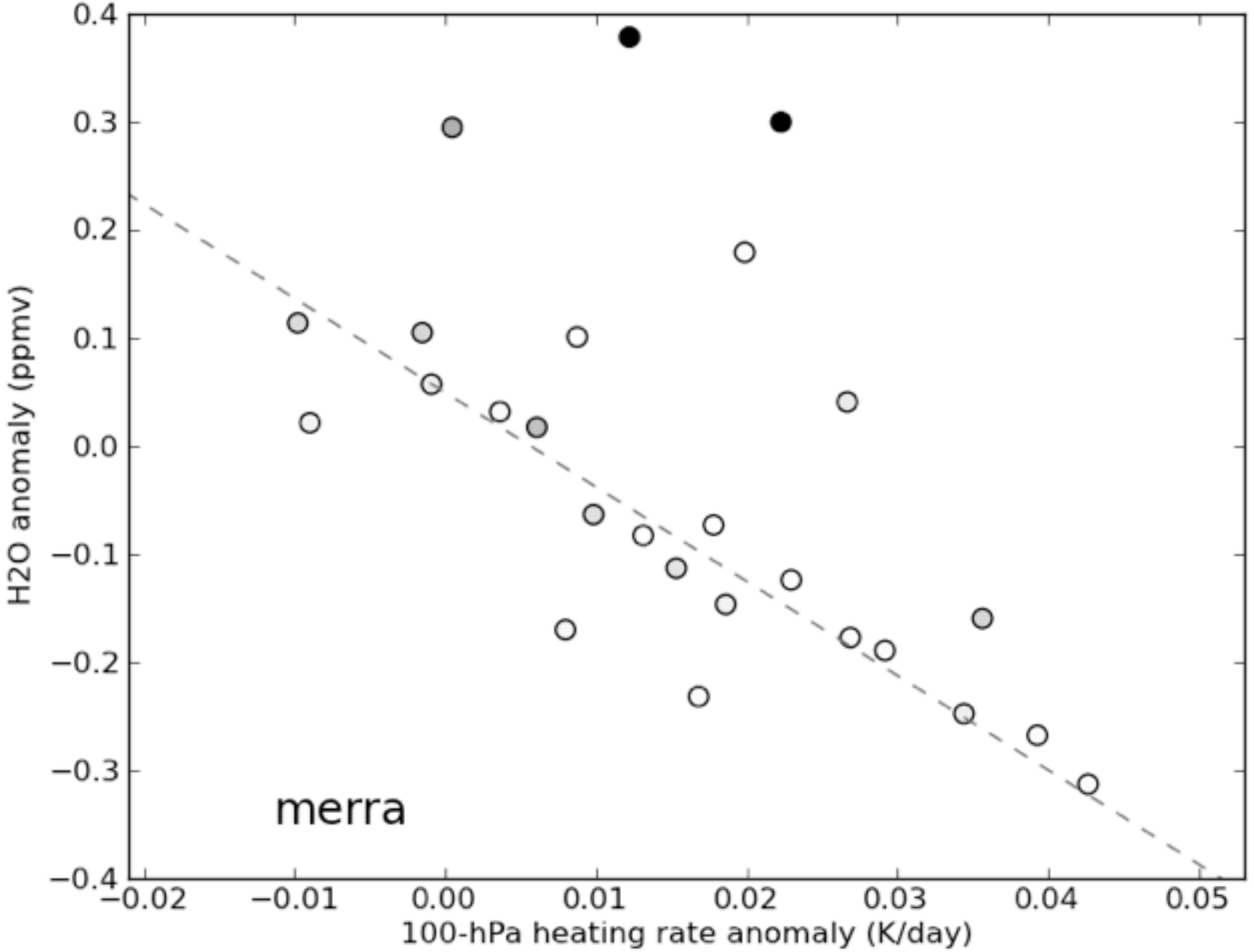
Aerosol data: Vernier, J. P., et al. (2011), Geophys. Res. Lett., 38, L12807, doi:10.1029/2011gl047563.

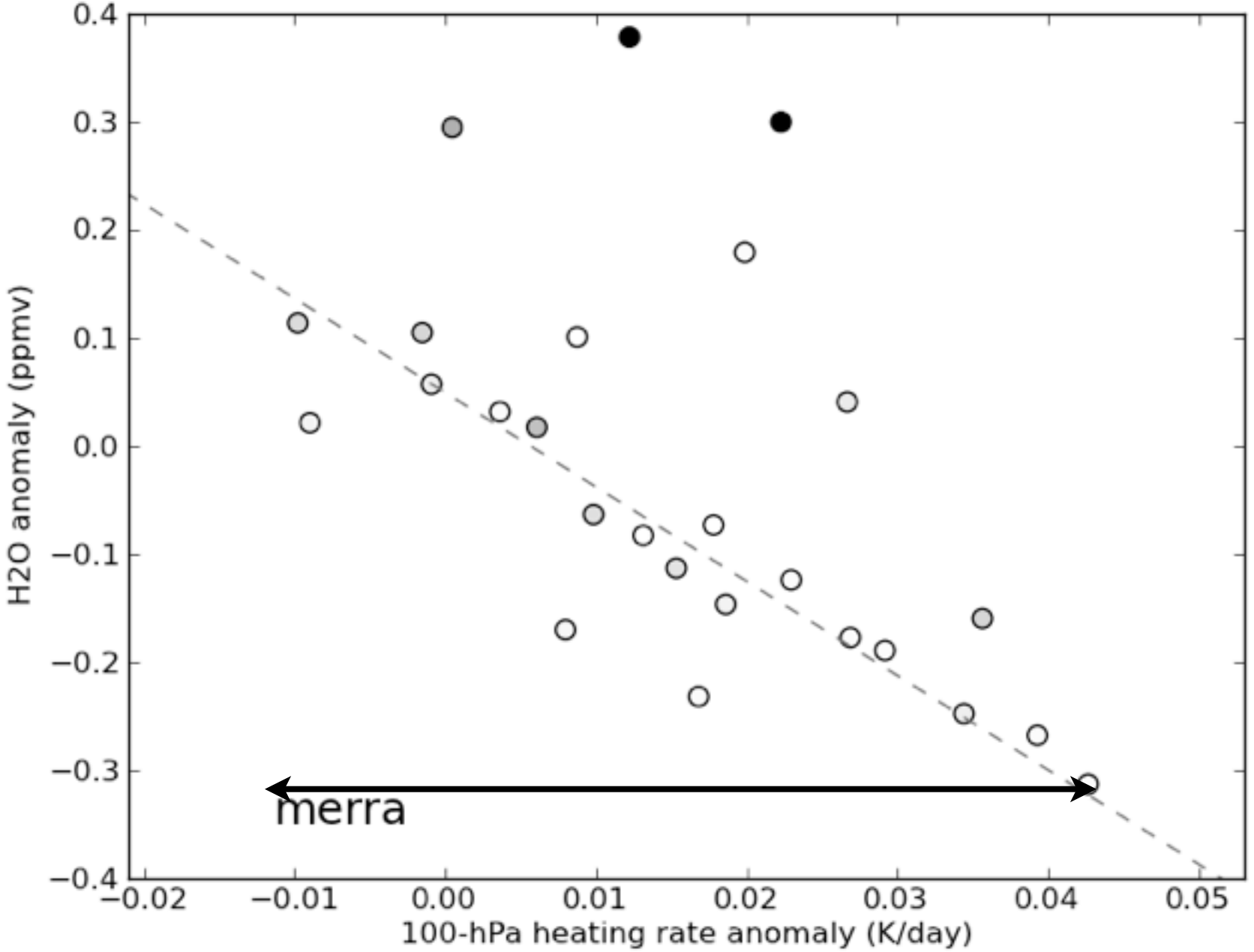

0.4
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
−0.4
H2O anomaly (ppmv)
−0.02
−0.01
0.00
0.01
0.02
0.03
0.04
0.05
100-hPa heating rate anomaly (K/day)
merra

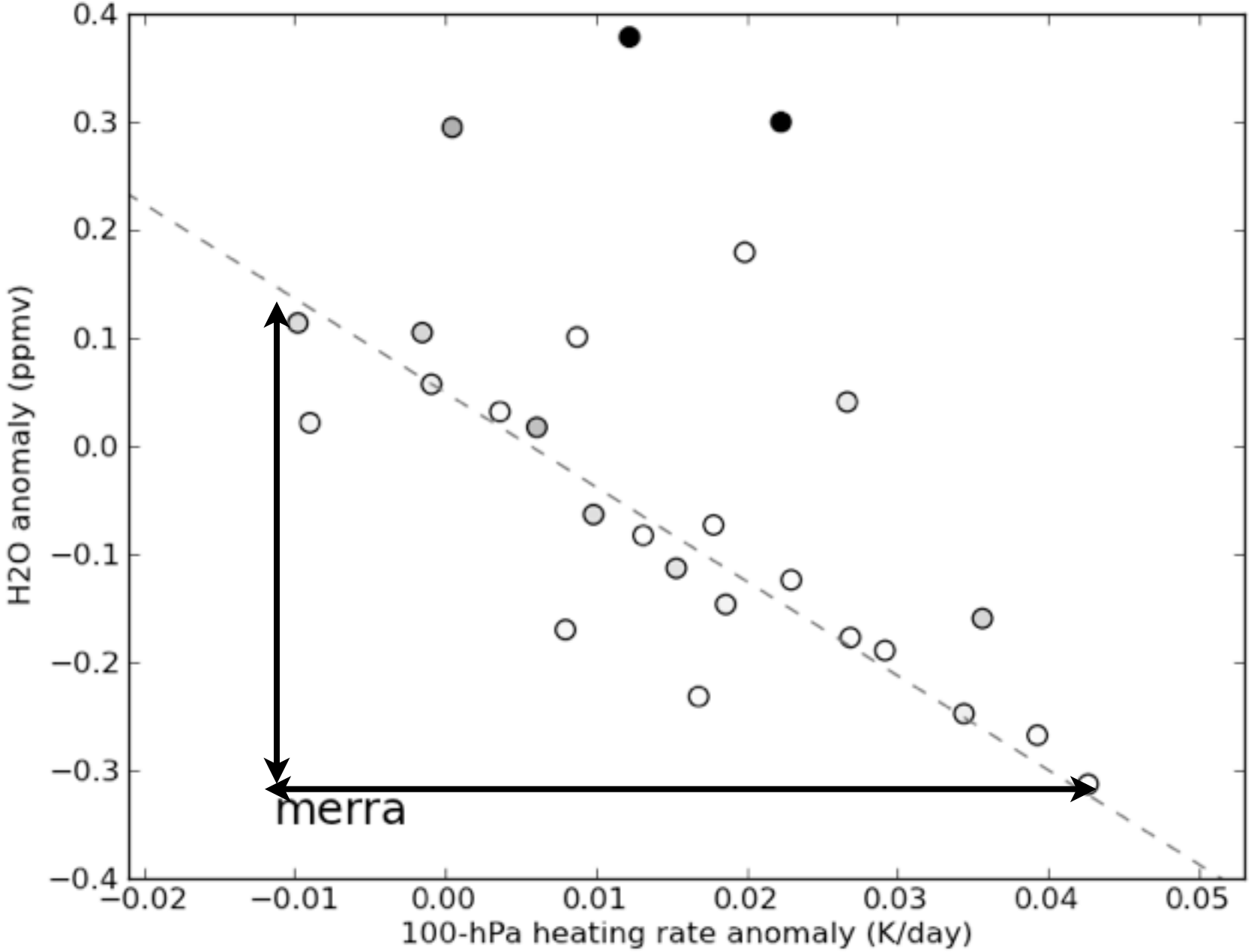

Volcanic perturabation
due to warmer TTL
merra
H2O anomaly (ppmv)
100-hPa heating rate anomaly (K/day)
0.4
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
−0.4
−0.02
−0.01
0.00
0.01
0.02
0.03
0.04
0.05

What controls interannual variability of stratospheric water?

QBO	0.45 ppmv
ENSO	~ zero
Mt. Pinatubo	0.2-0.4 ppmv


0.4
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
−0.4
H2O anomaly (ppmv)
−0.02
−0.01
0.00
0.01
0.02
0.03
0.04
0.05
100-hPa heating rate anomaly (K/day)
merra


0.4
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
−0.4
H2O anomaly (ppmv)
−0.02
−0.01
0.00
0.01
0.02
0.03
0.04
0.05
100-hPa heating rate anomaly (K/day)
merra


0.4
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
−0.4
H2O anomaly (ppmv)
−0.02
−0.01
0.00
0.01
0.02
0.03
0.04
0.05
100-hPa heating rate anomaly (K/day)
merra

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QBO	0.45 ppmv
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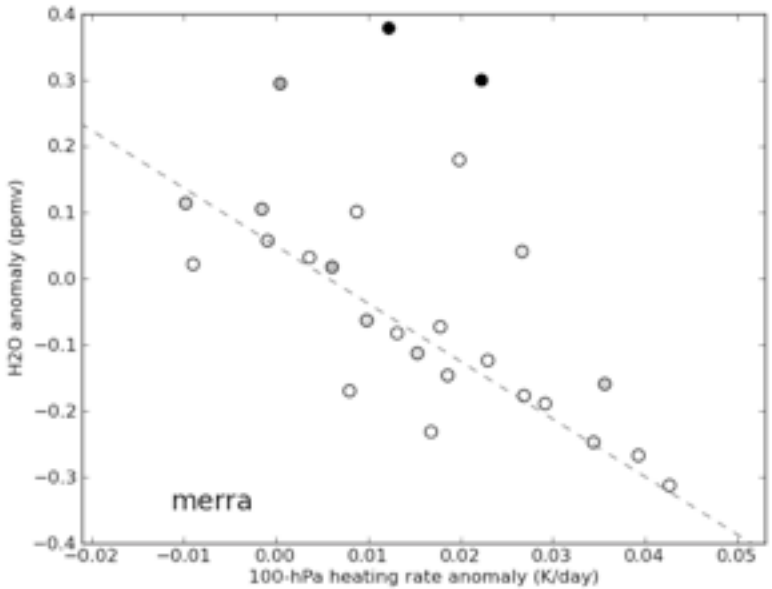
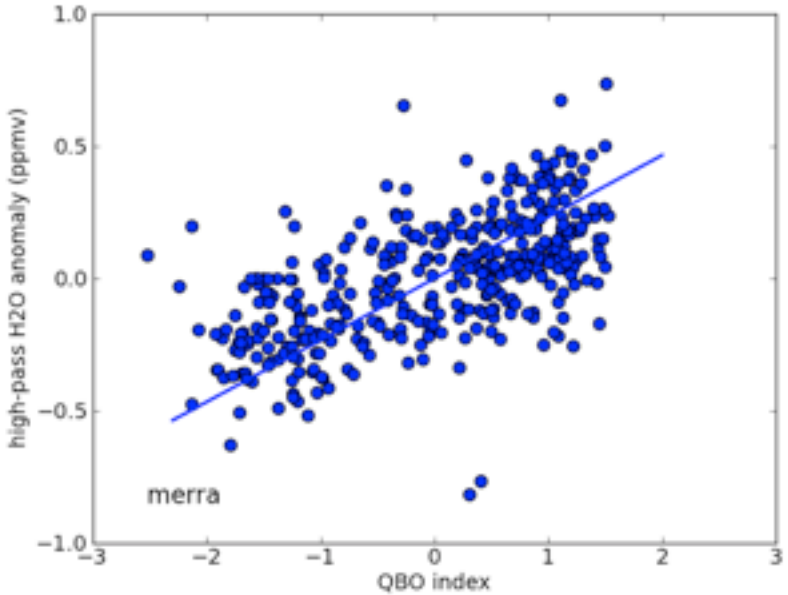
$H2O^*_{proxy} = -8.7*Q^{dot}_f + 0.23*QBO$

BD circulation

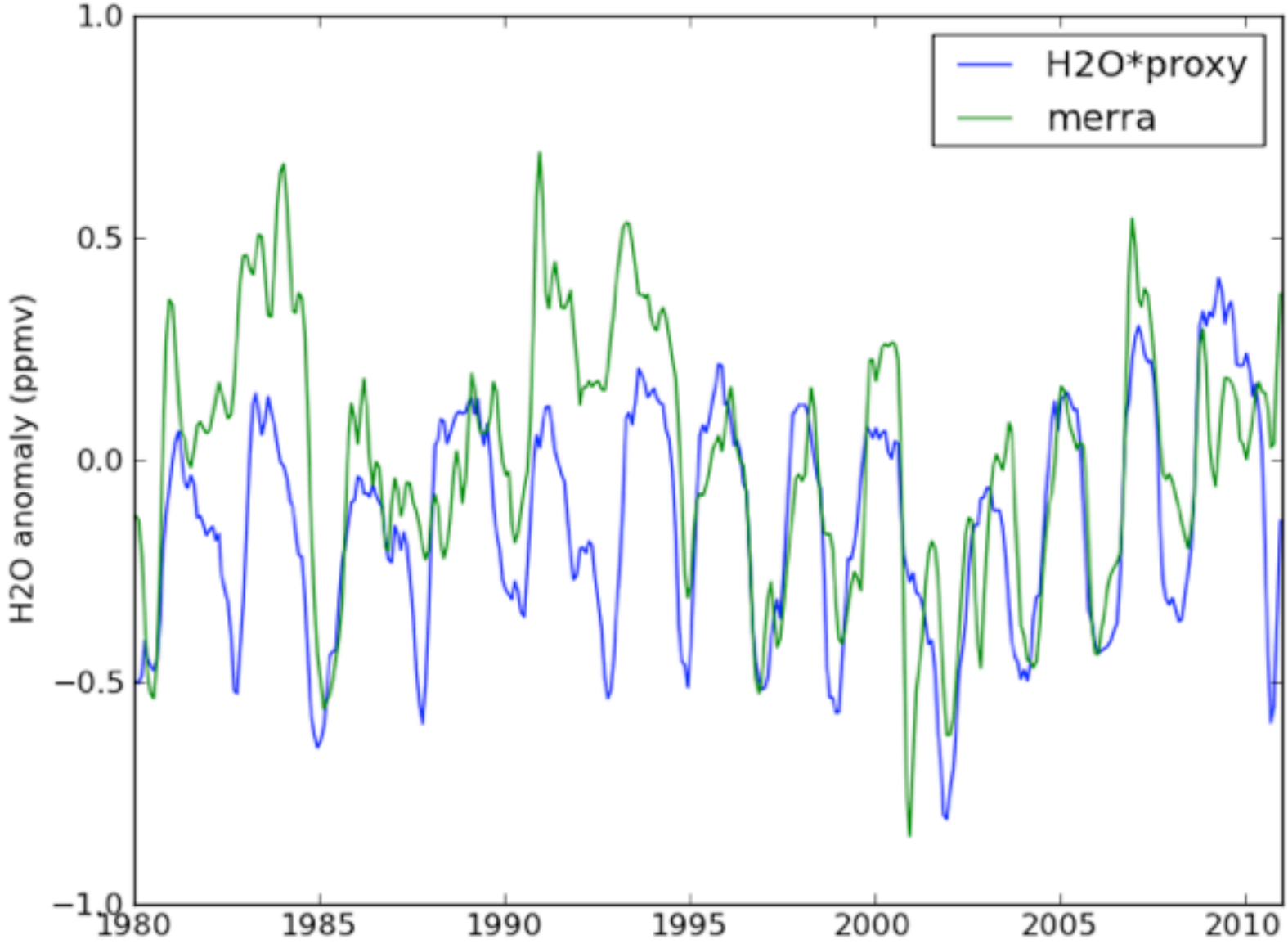


QBO



Green line is the model

Blue line is a proxy $H2O^* = -8.7*Q^{dot}_f + 0.23*QBO$



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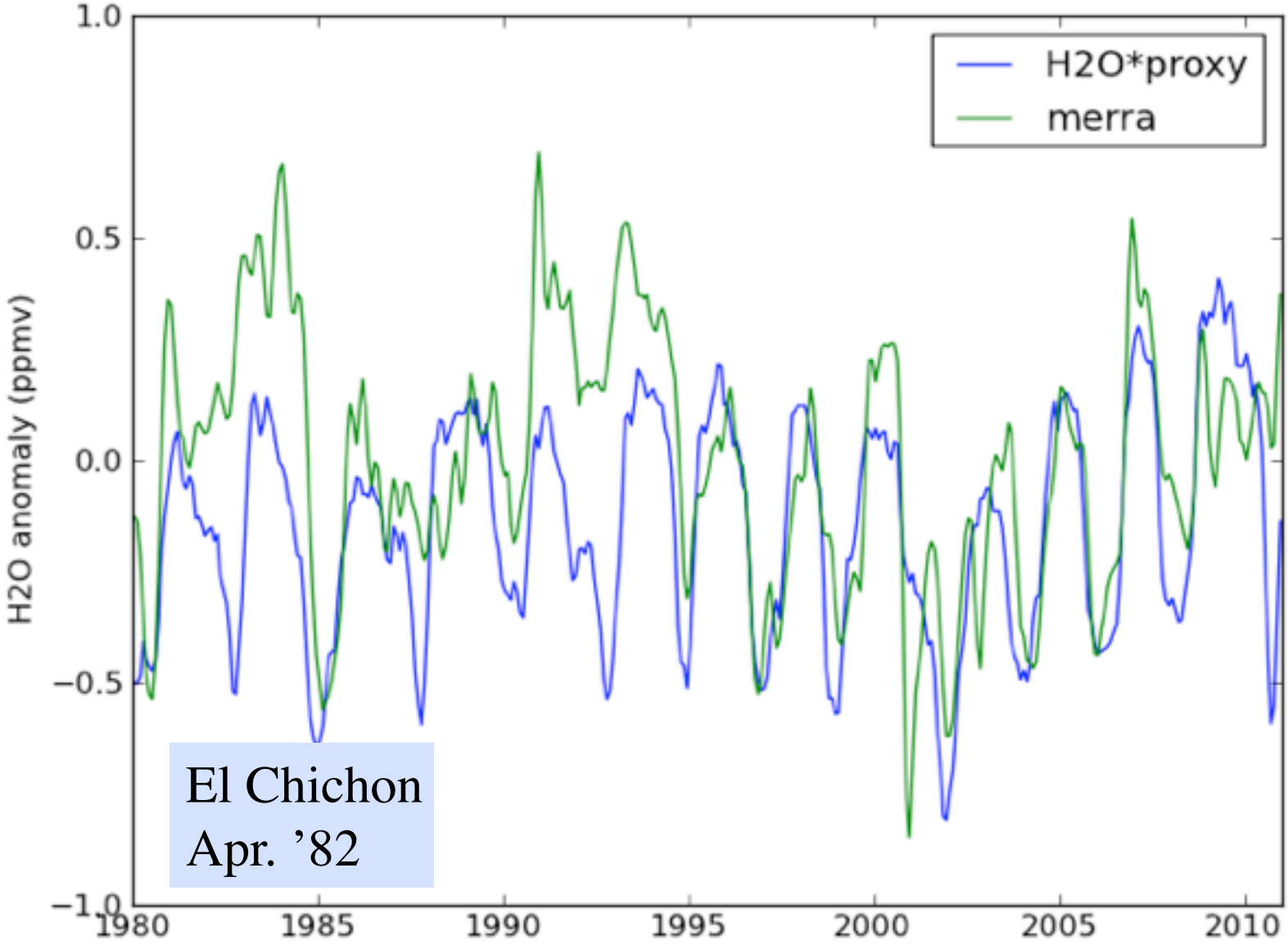
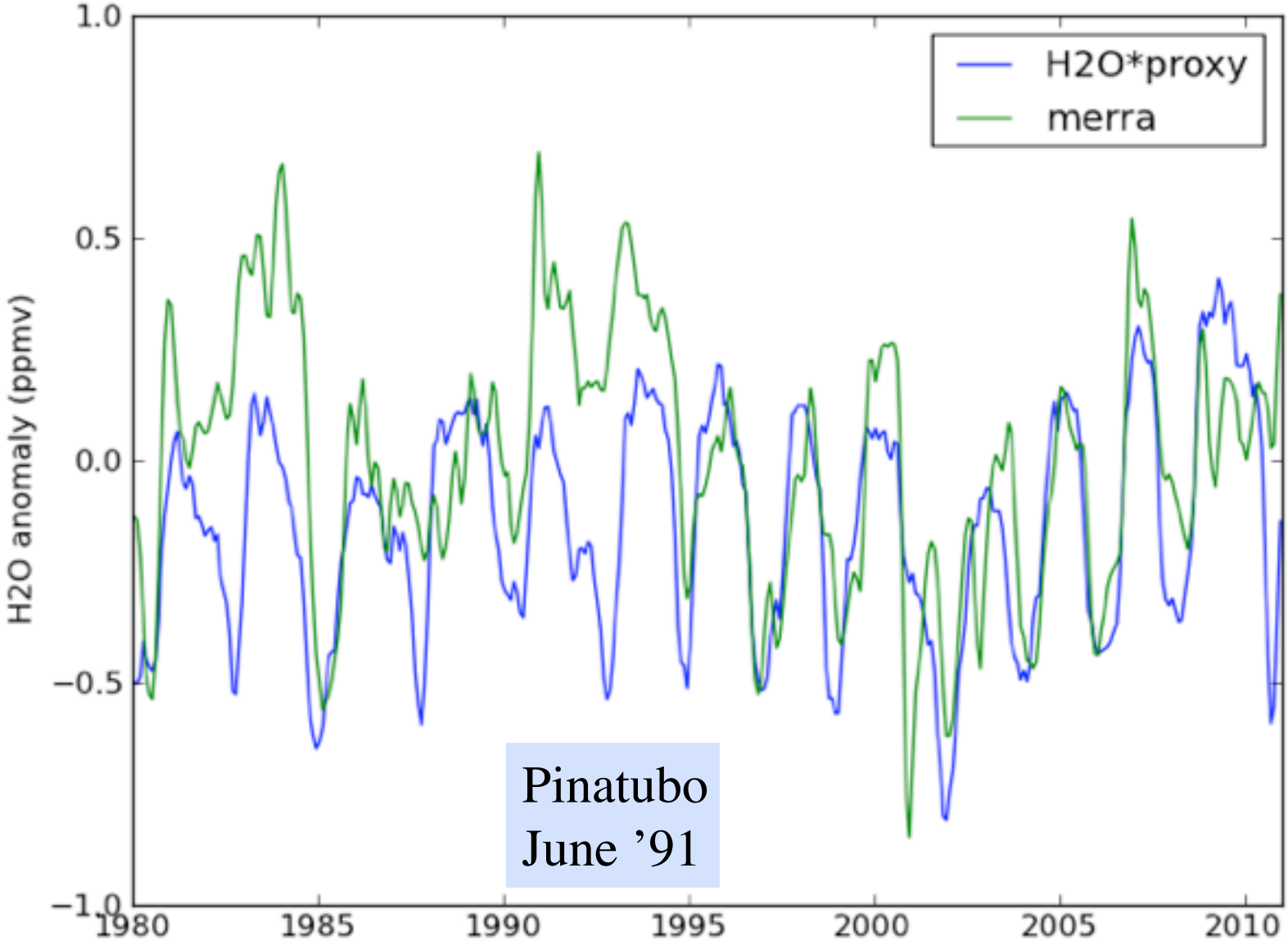


Green line is the model

Blue line is a proxy $H2O^* = -8.7*Q^{dot}_f + 0.23*QBO$



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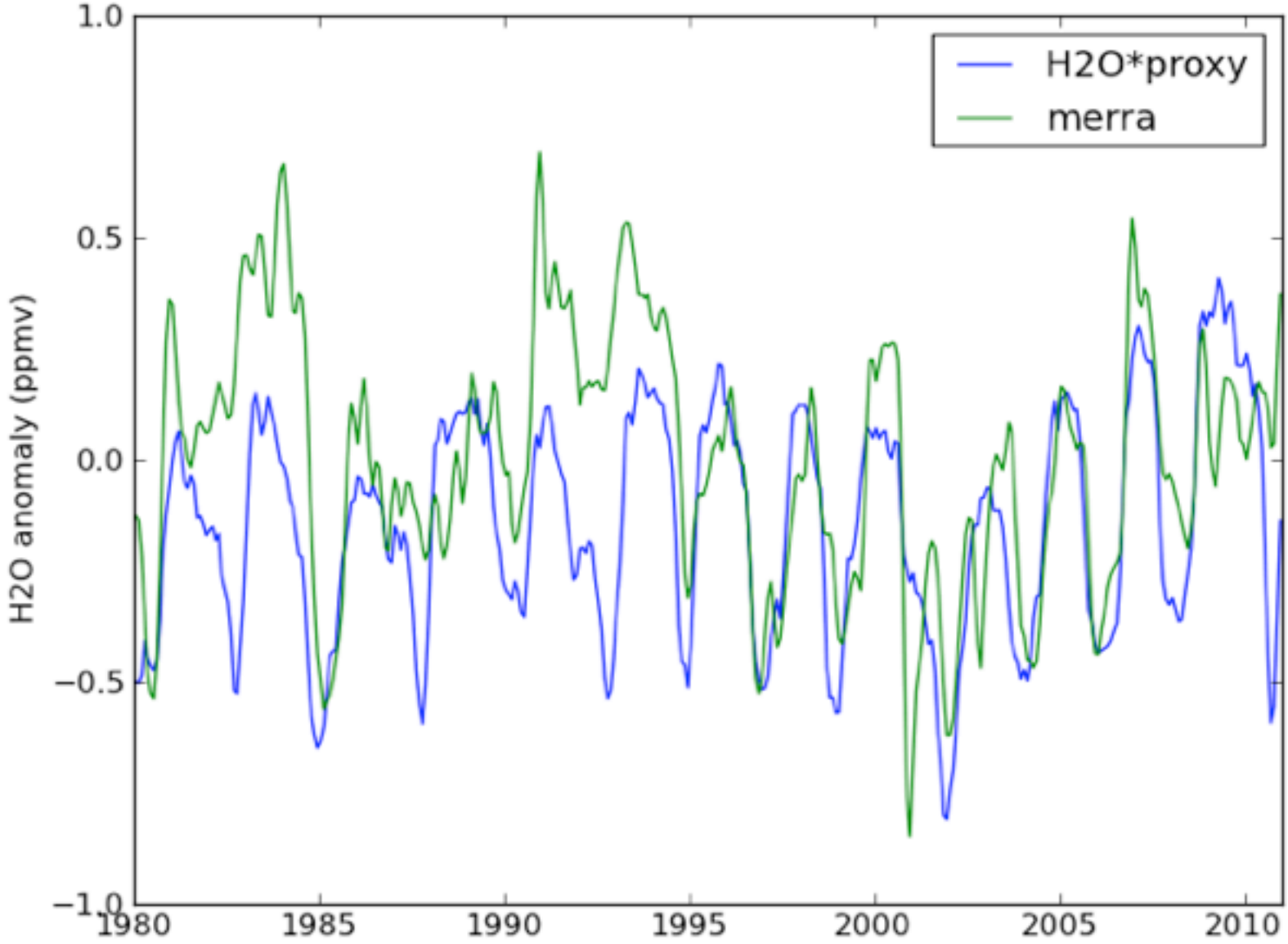

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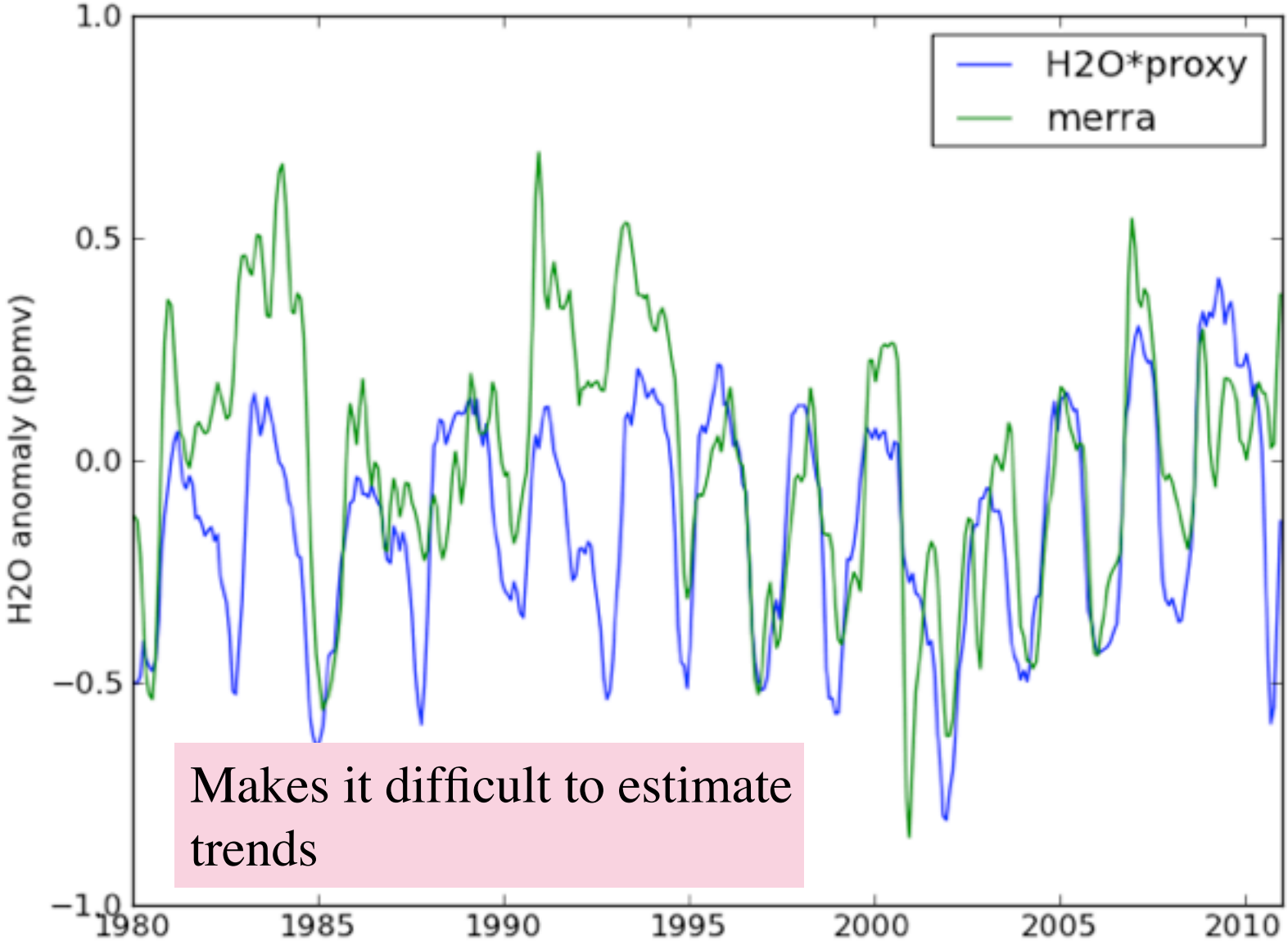
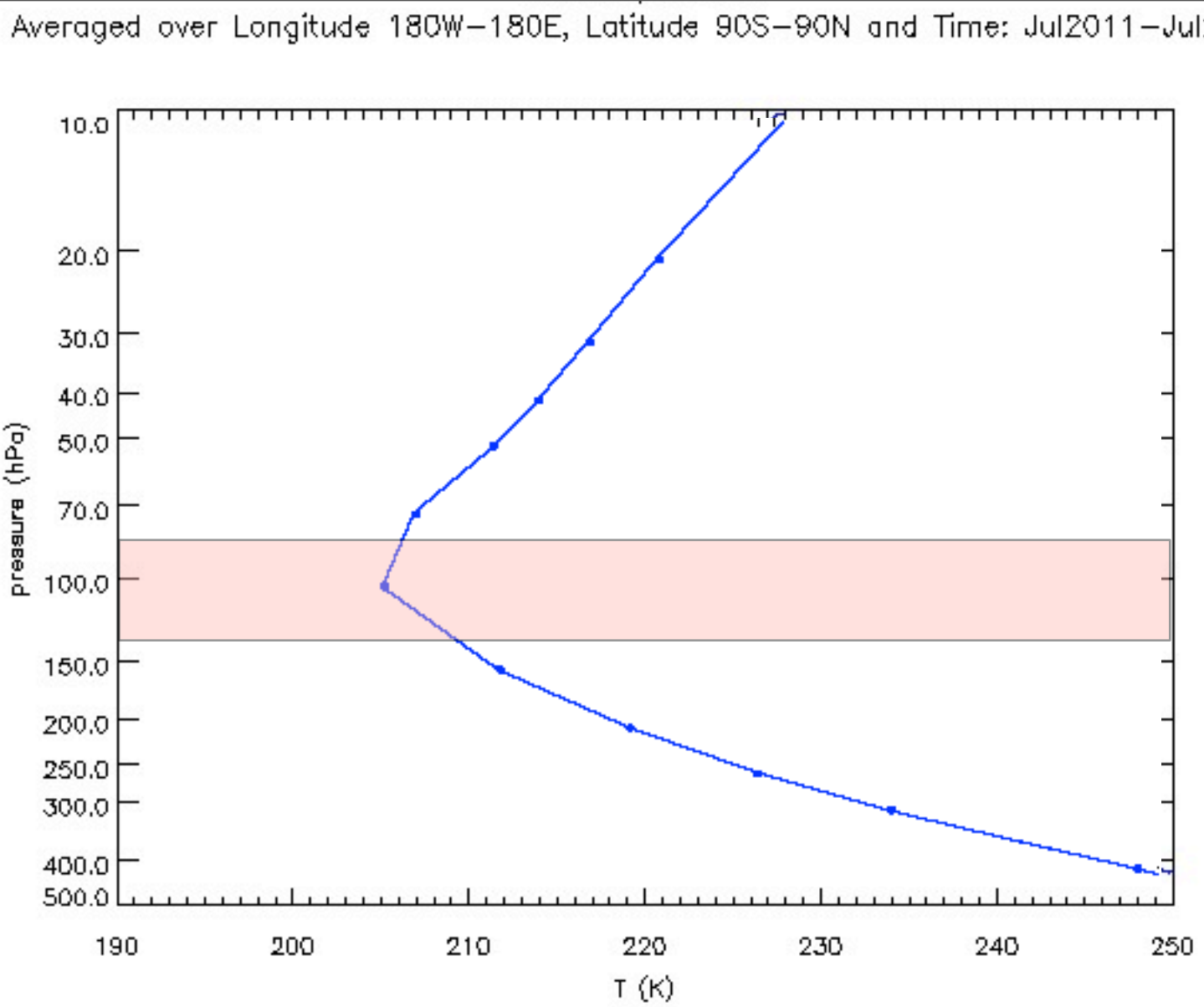


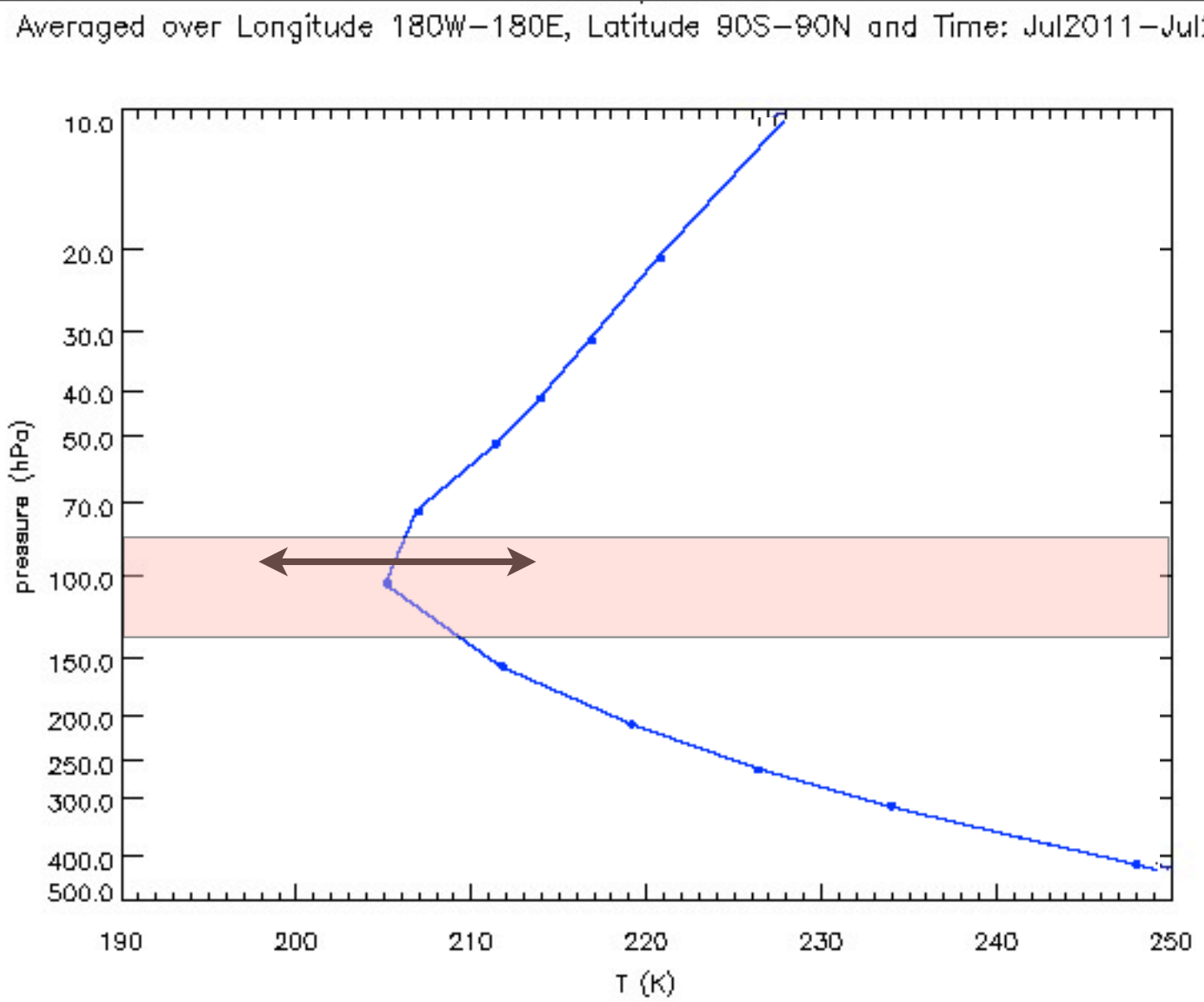
Makes it difficult to estimate trends

Scorecard

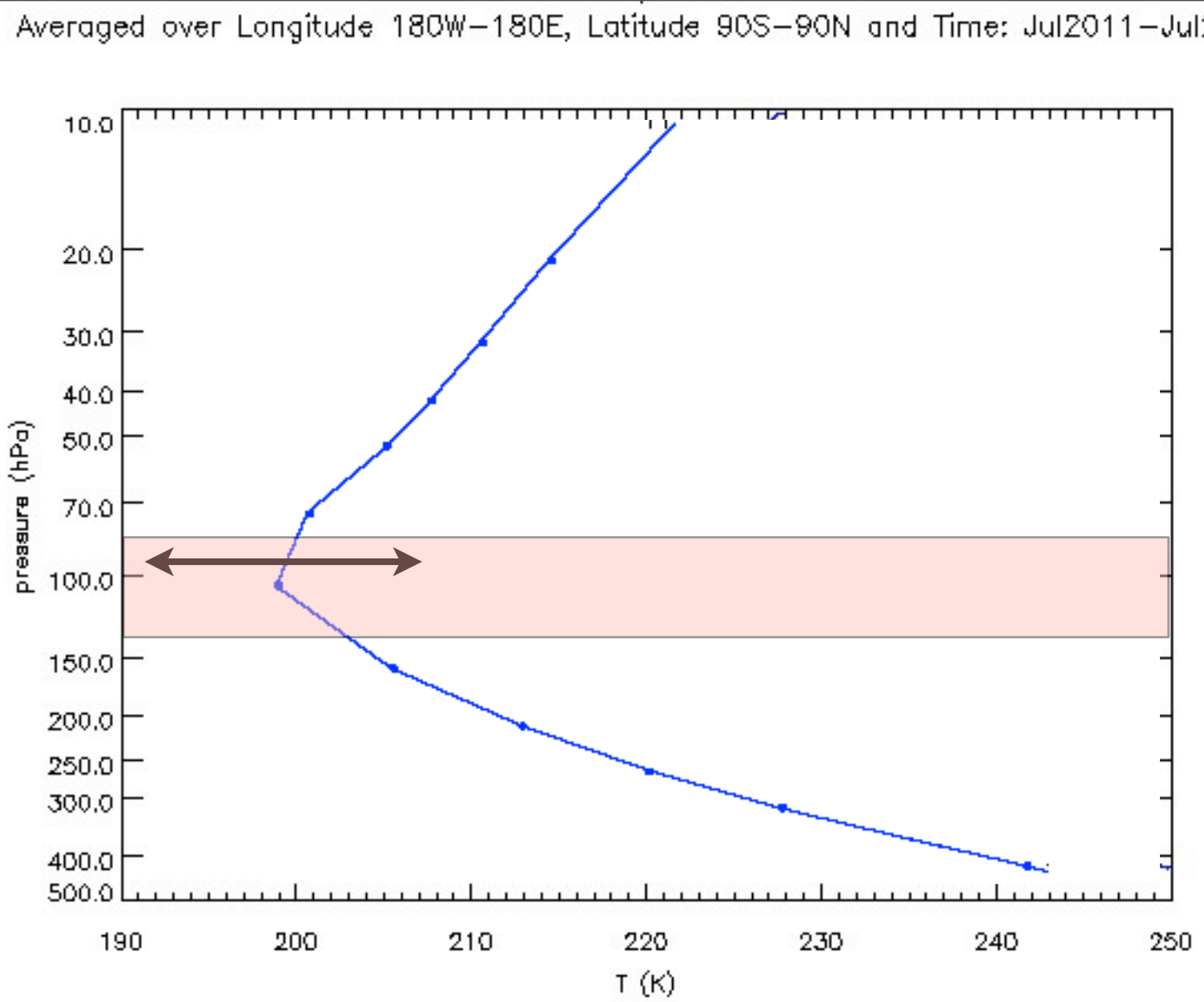
- Successfully analyzed the past few decades
- But what does this tell us about the future?
- Models predict an increase in water entering the stratosphere
- Why?



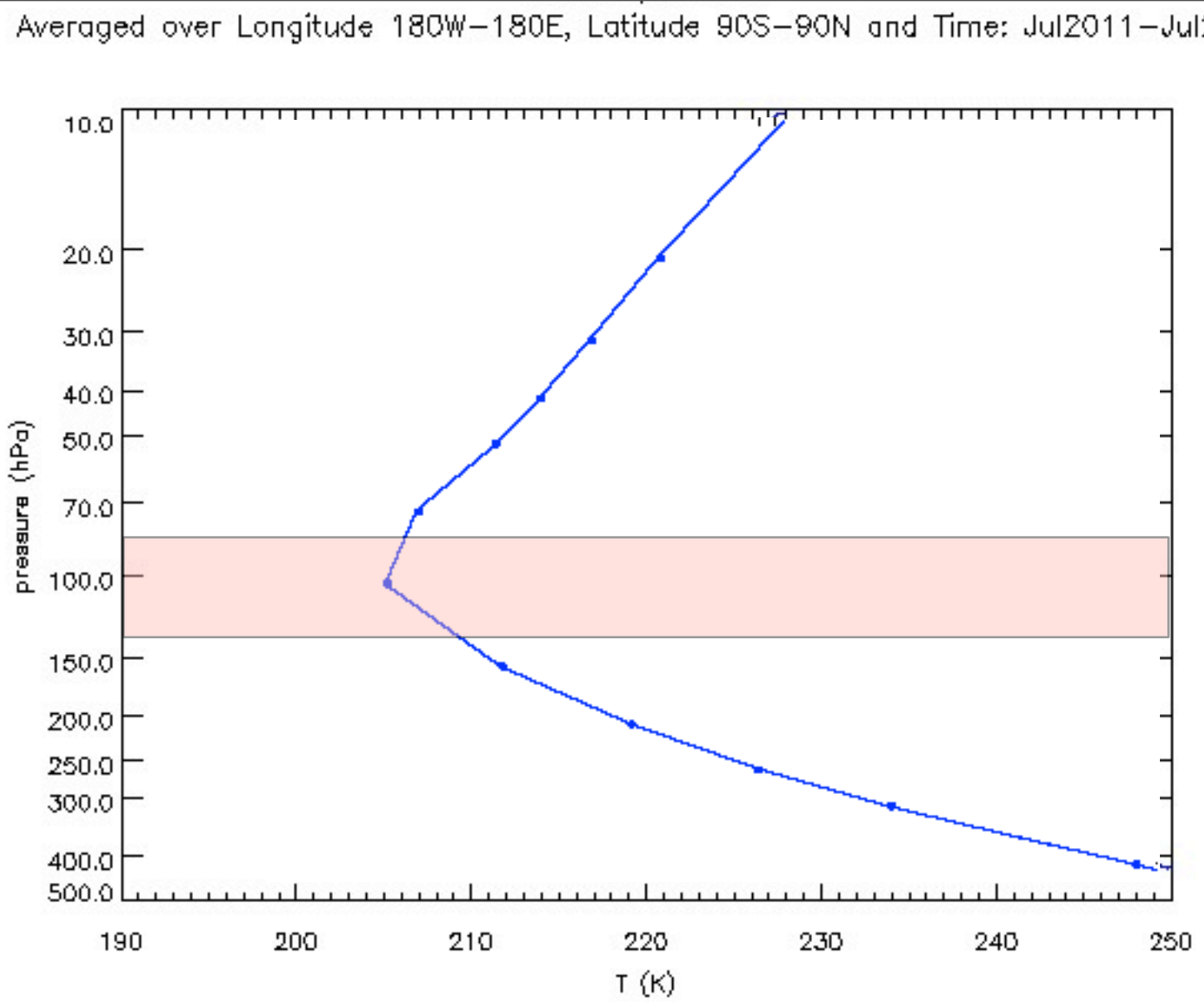
MERRA reanalysis



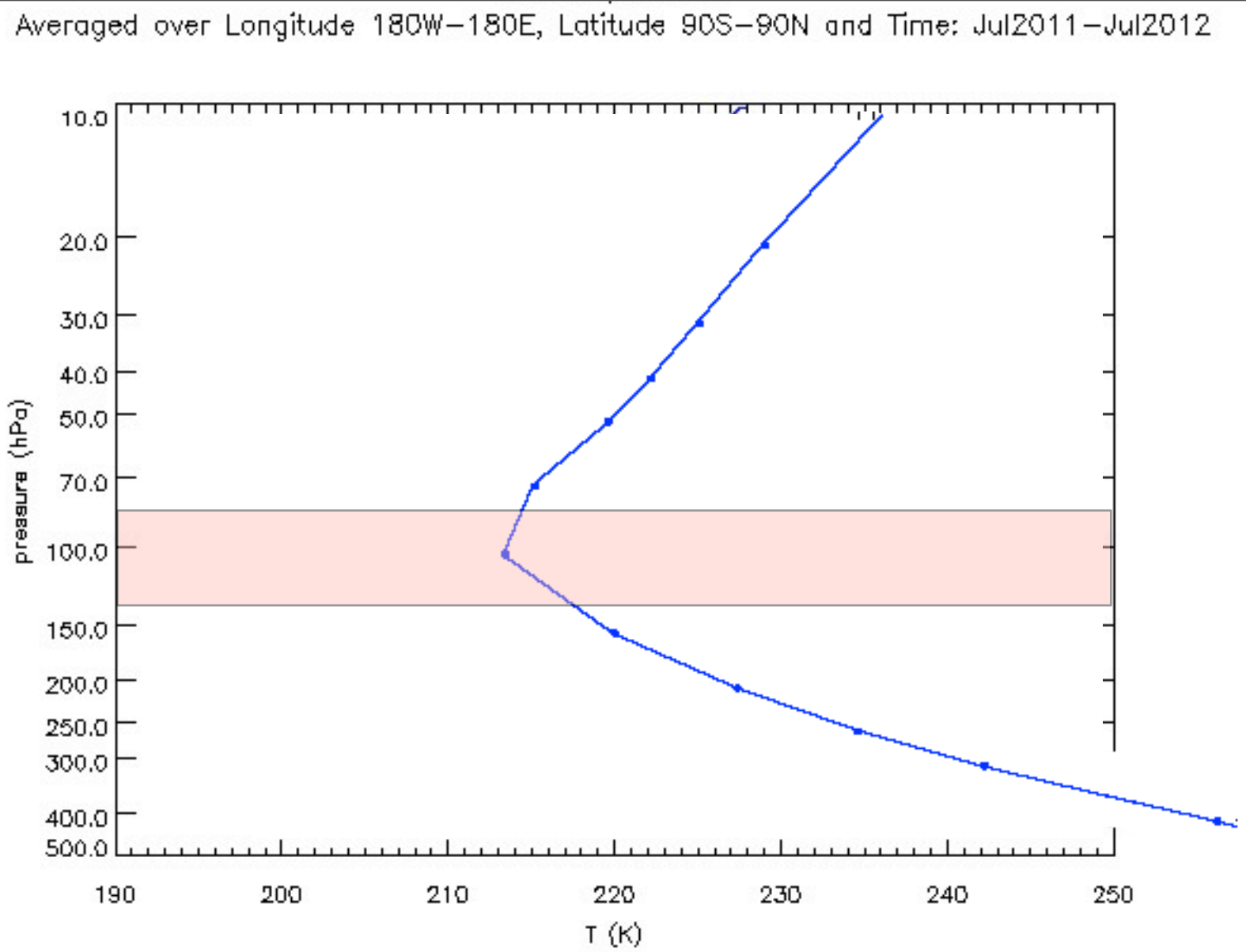
MERRA reanalysis



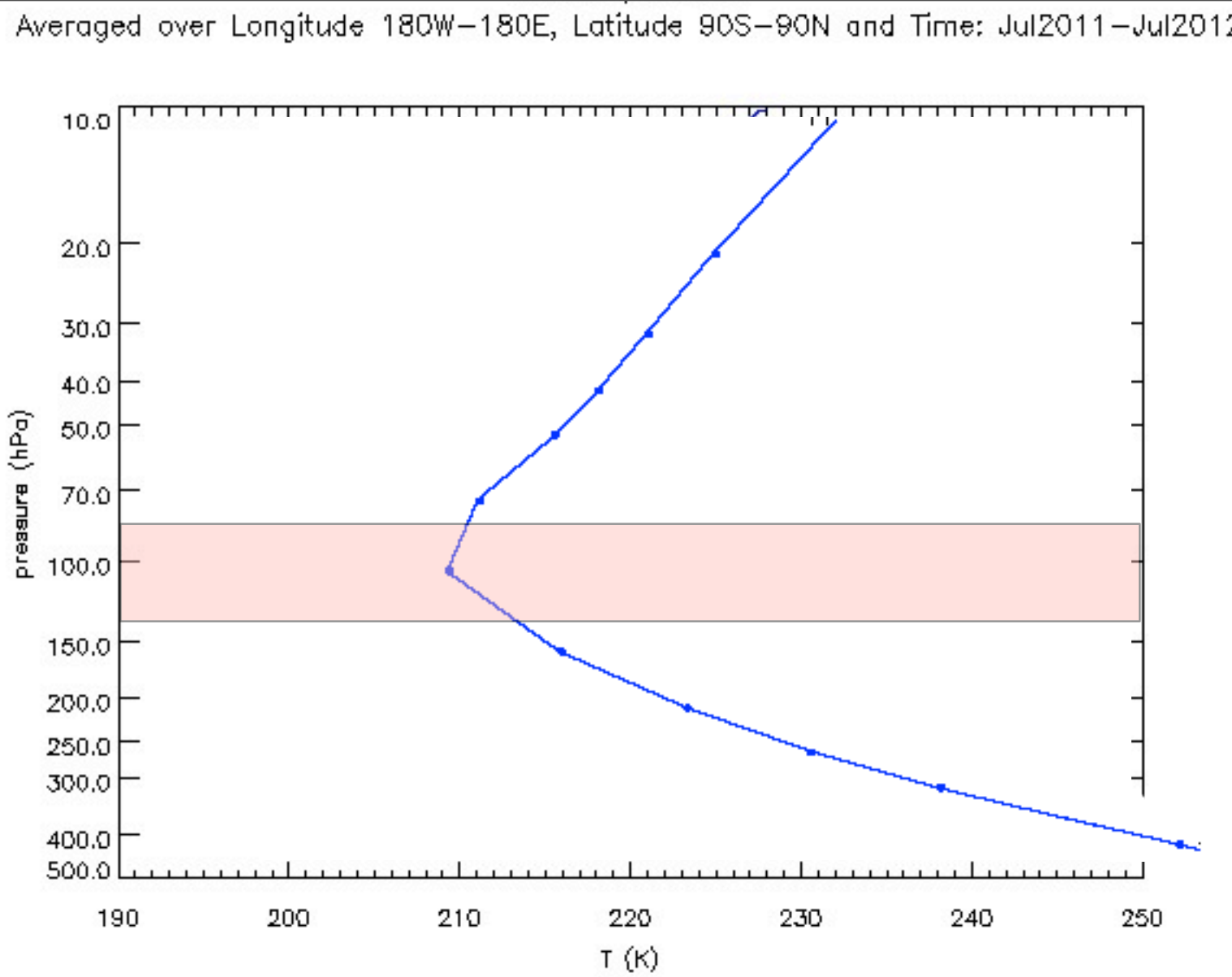
MERRA reanalysis



MERRA reanalysis



MERRA reanalysis



MERRA reanalysis

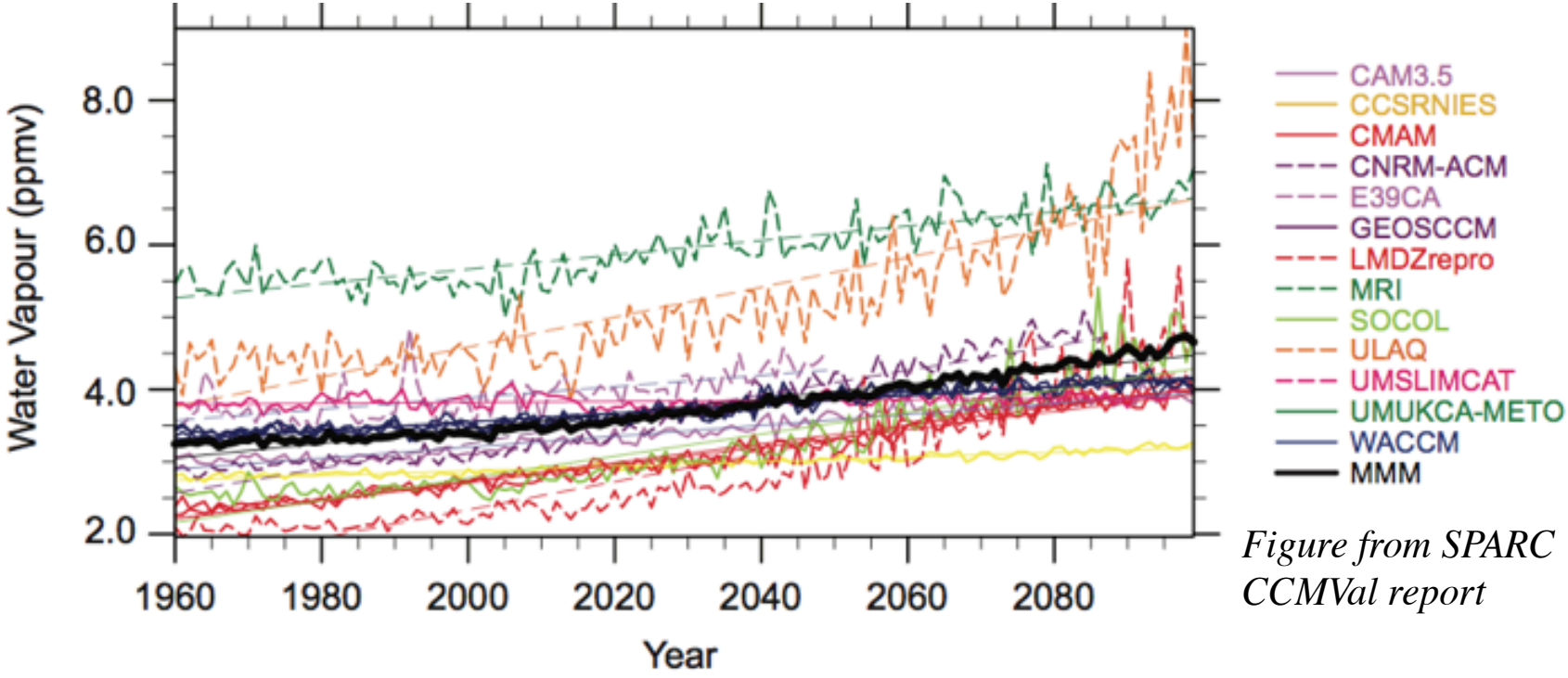


Figure from SPARC CCMVal report

ΔH_2O = (warming of the TTL)-
(increased strength of BD circulation)

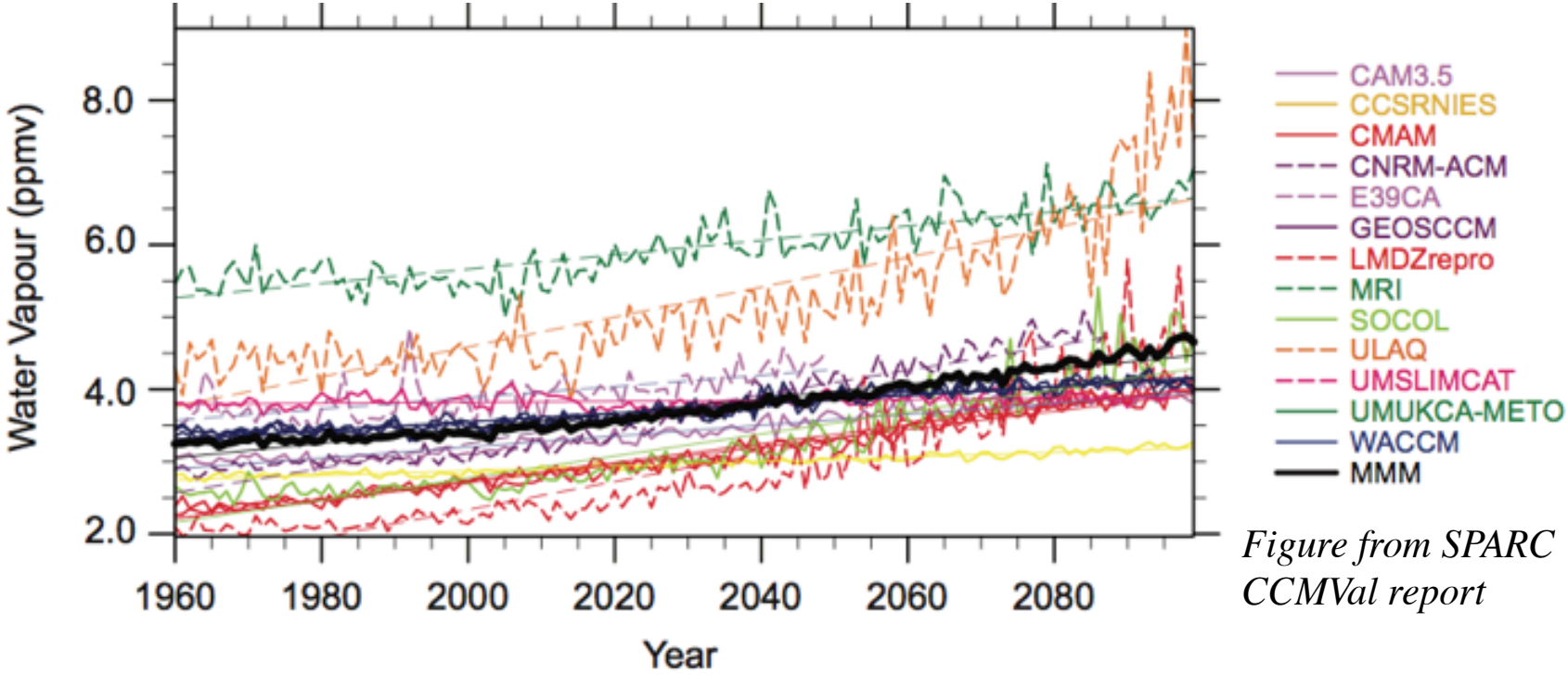


Figure from SPARC CCMVal report

ΔH_2O = (warming of the TTL)- (increased strength of BD circulation)

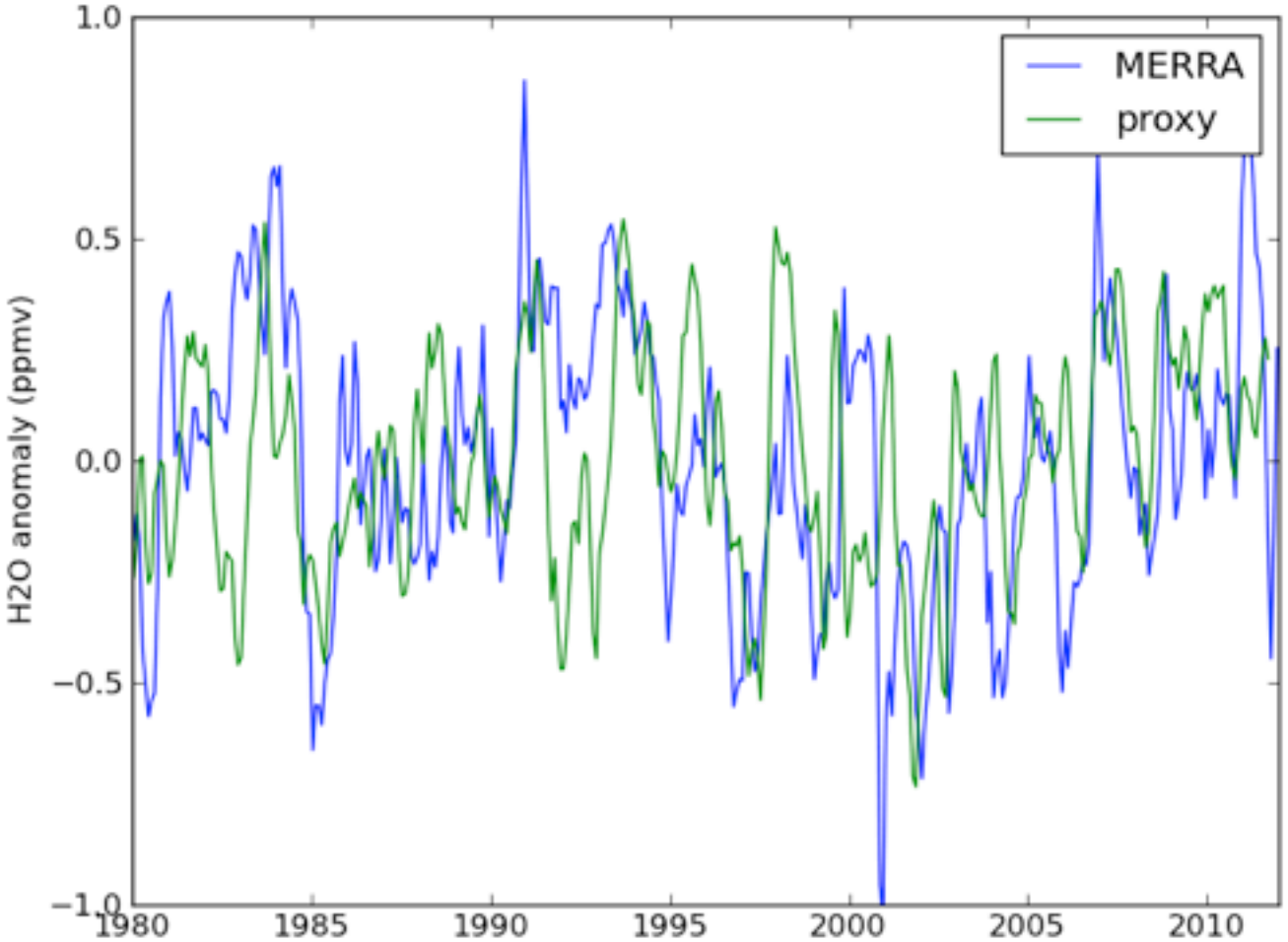
(warming of the TTL) > (increased strength of BD circulation) so $\Delta H_2O > 0$

Conclusions

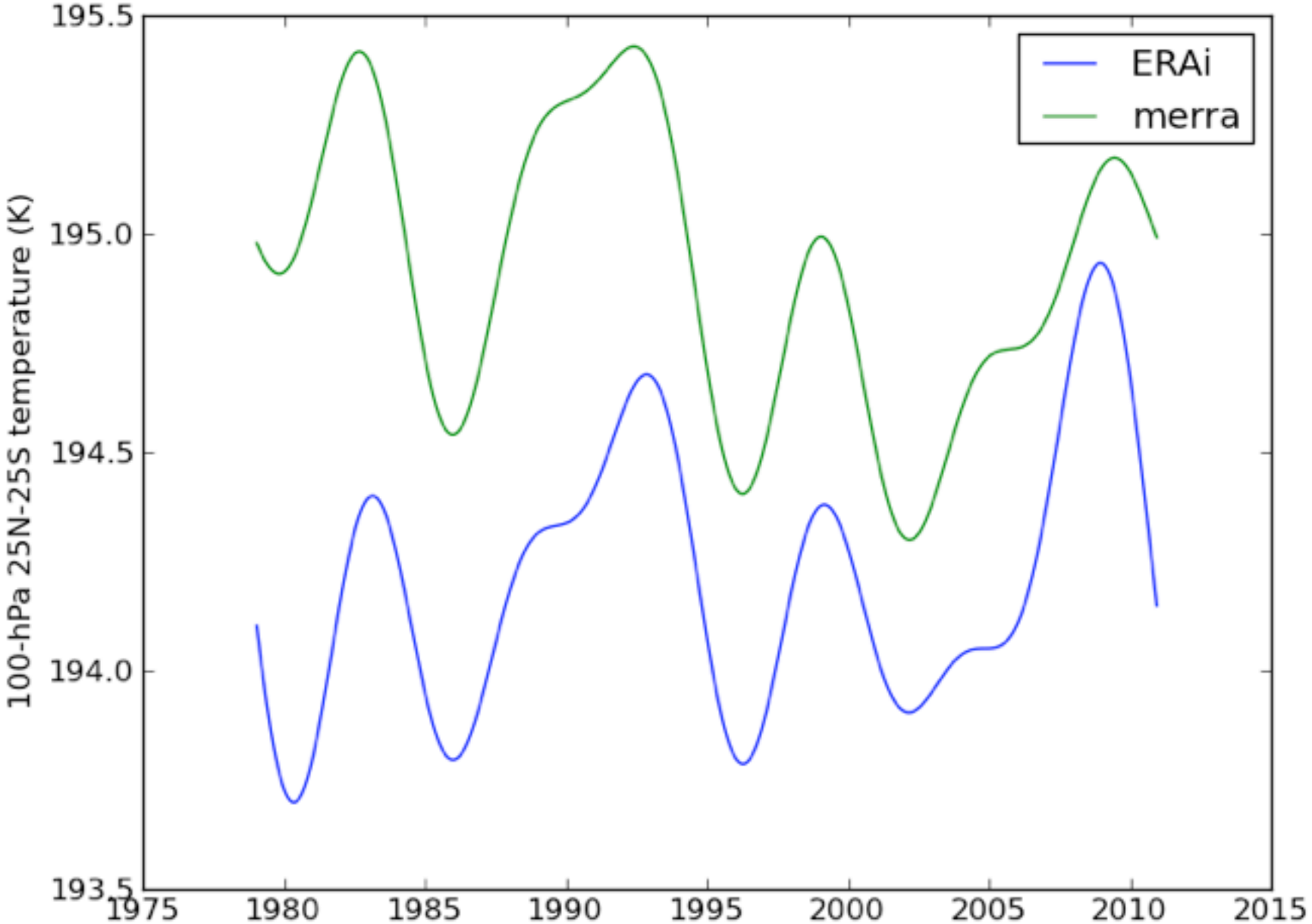
- Over the past few decades the fundamental control of H2O entry value = QBO, BD circulation, volcanoes
- Each affects stratospheric entry value by ~0.4-0.5 ppmv
- In the upcoming century, (ATM) warming of the TTL drives a long-term increase; stronger BD circulation offsets some of that increase
  - warming of the TTL dominates
- Contact me if you want the trajectories

Proxy = C*Qdot

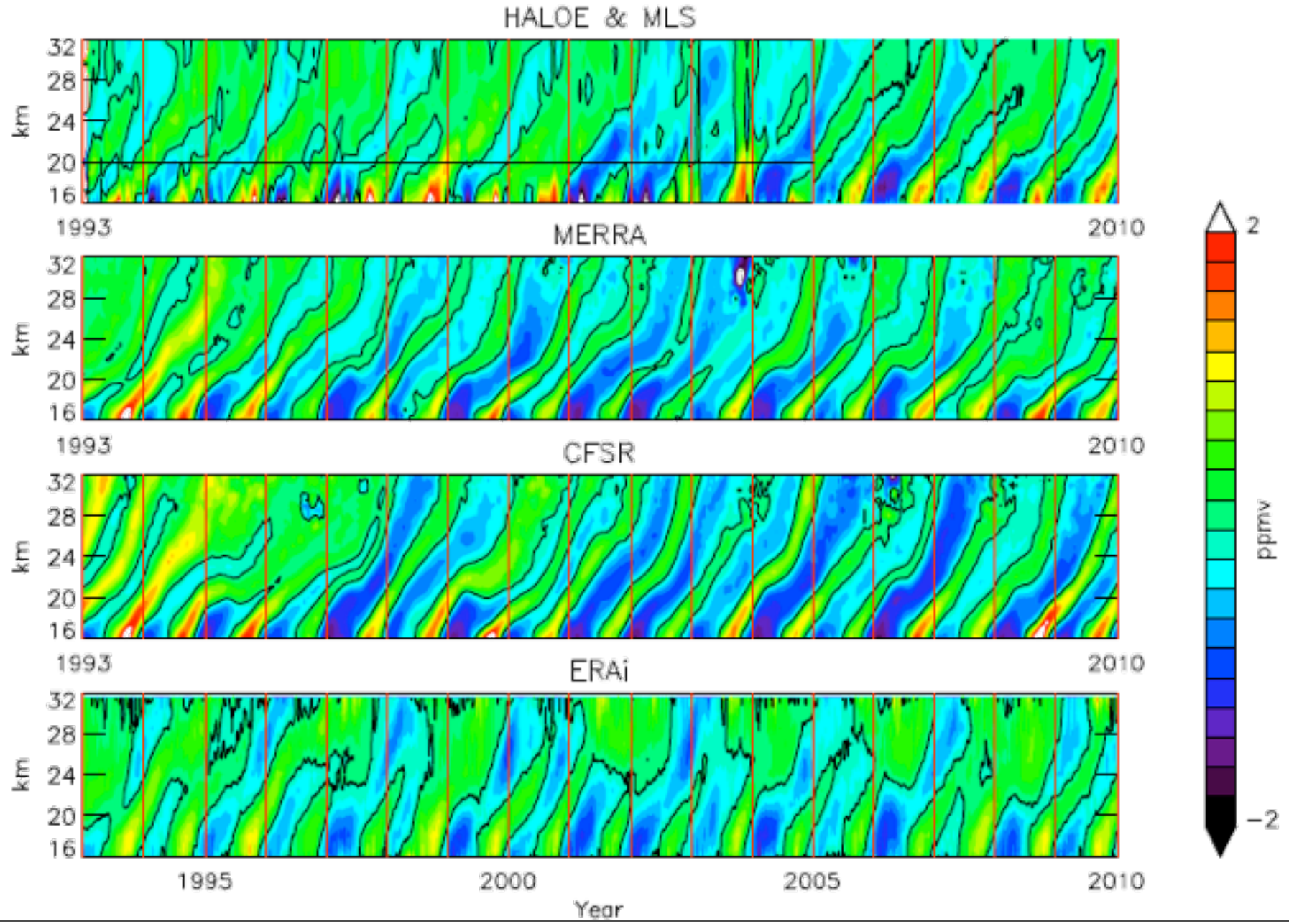
C is from an EOF fit between Qdot and H2O*

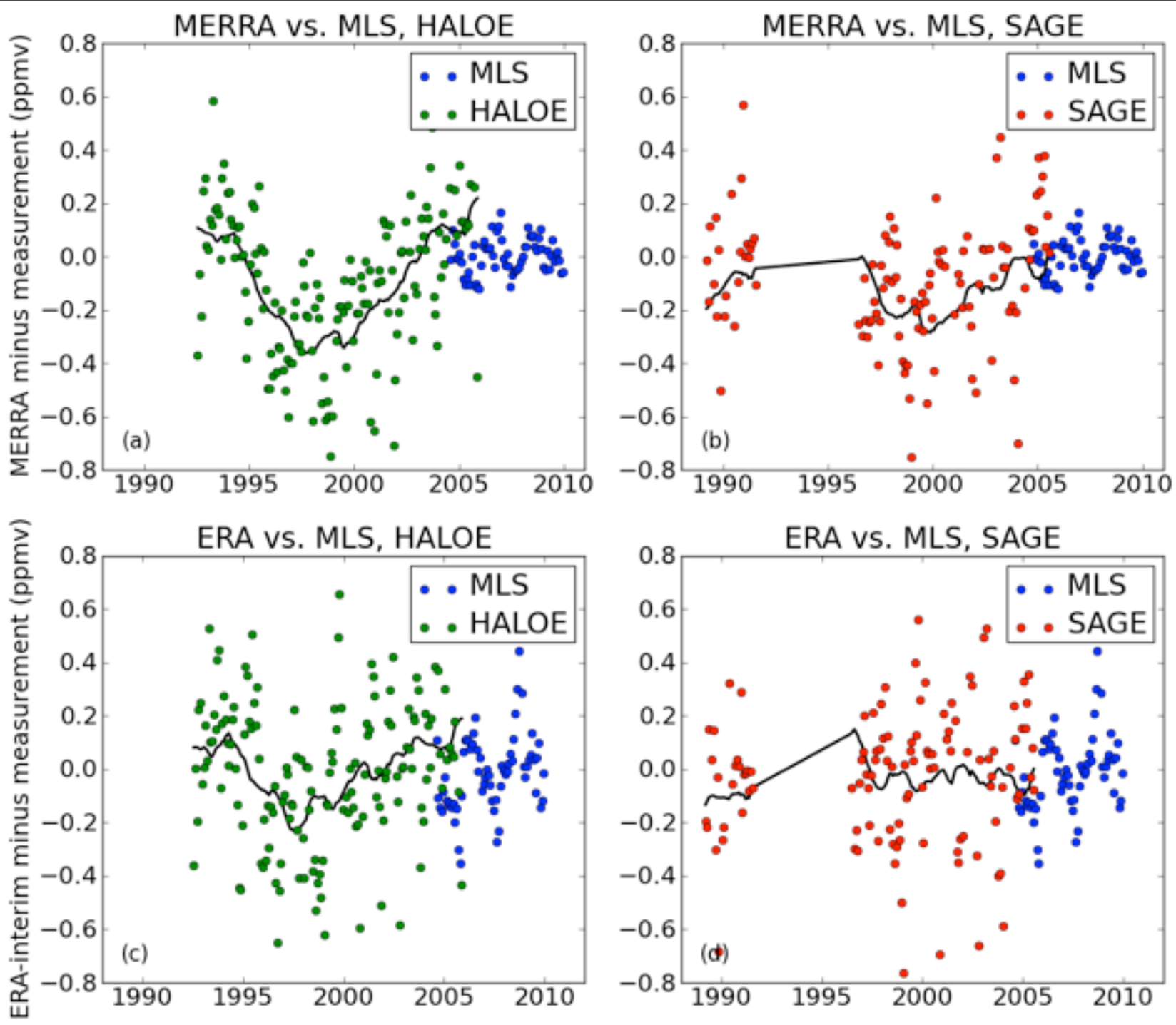


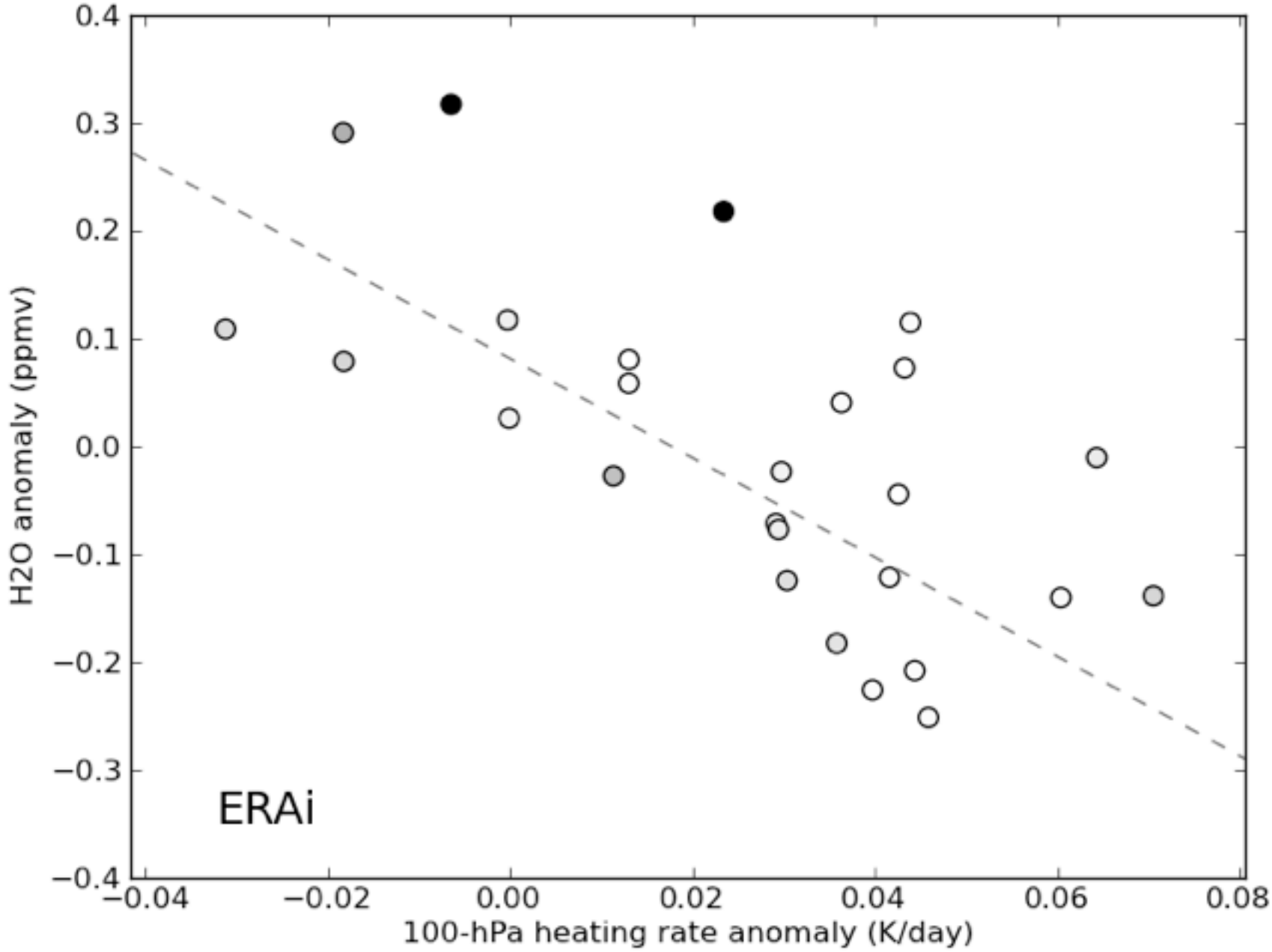
Data are low-pass filtered



Tropical Tape Recorder

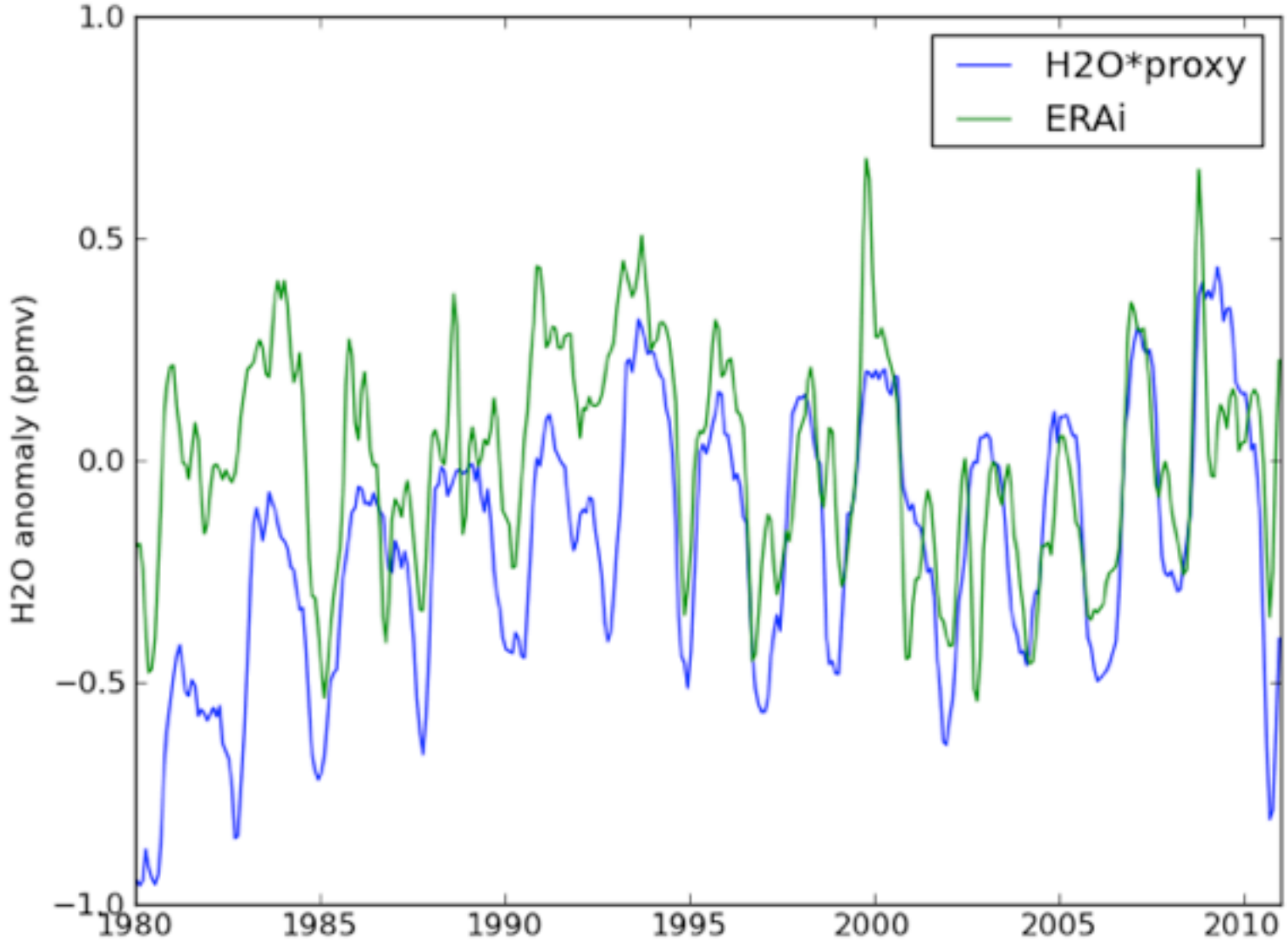


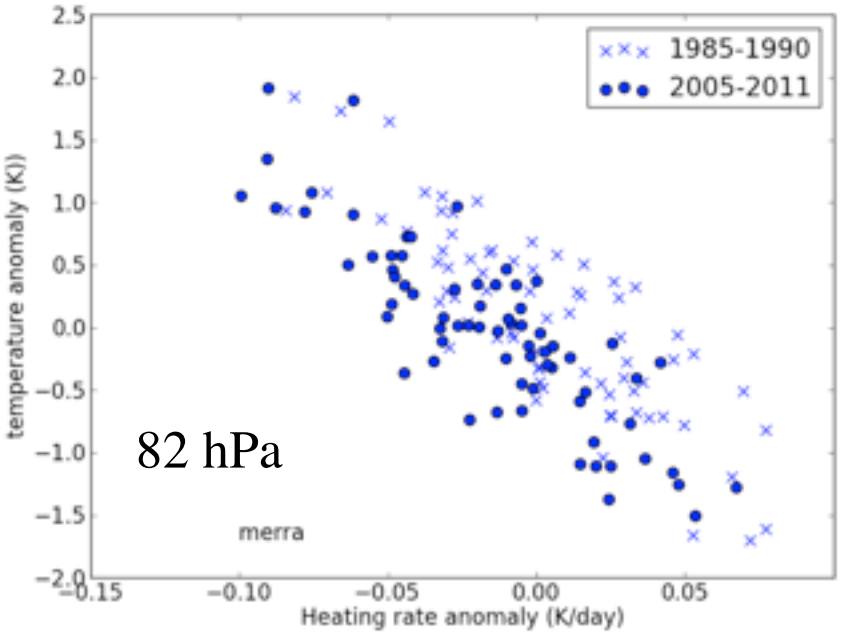

MERRA vs. MLS, HALOE
MERRA vs. MLS, SAGE
ERA vs. MLS, HALOE
ERA vs. MLS, SAGE
MERRA minus measurement (ppmv)
ERA-interim minus measurement (ppmv)
MLS
HALOE
SAGE
(a)
(b)
(c)
(d)
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
1990
1995
2000
2005
2010

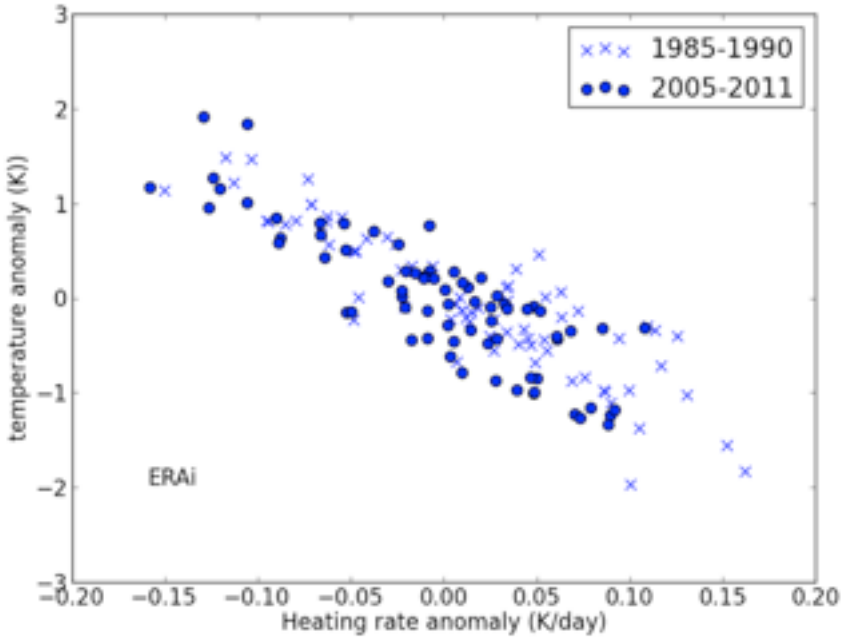

0.4
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
−0.4
H2O anomaly (ppmv)
−0.04
−0.02
0.00
0.02
0.04
0.06
0.08
100-hPa heating rate anomaly (K/day)
ERAi

Green line is the model

Blue line is a proxy $H2O^* = -4.6*Q^{dot}_f + 0.22*QBO$





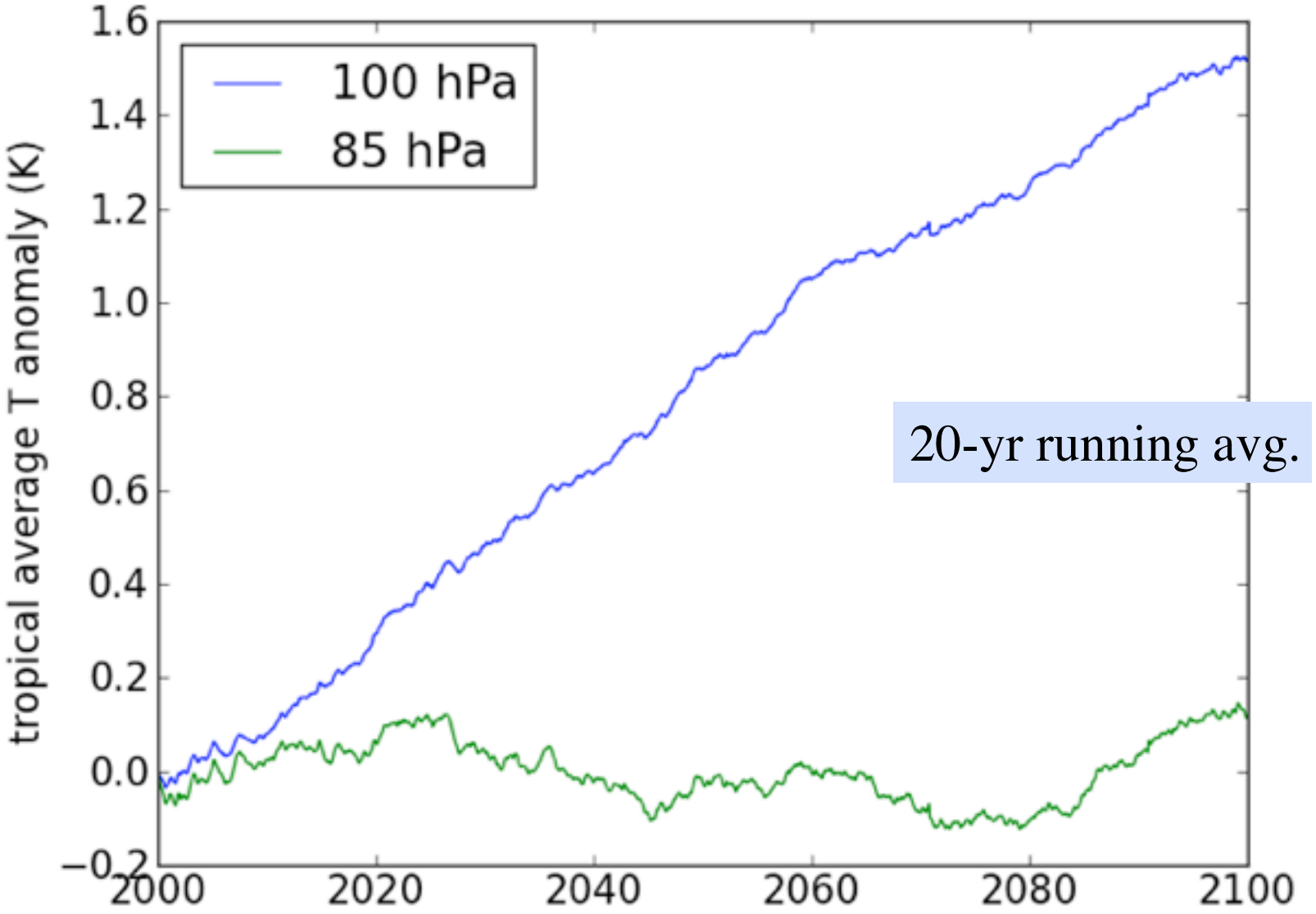


2005-10 minus 1985-90

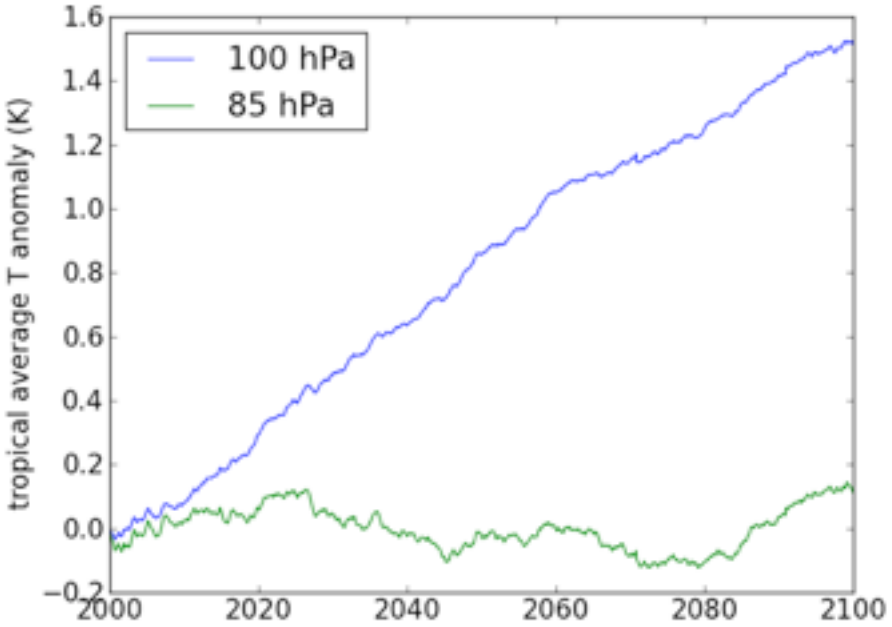
MERRA ΔT = -0.4 K

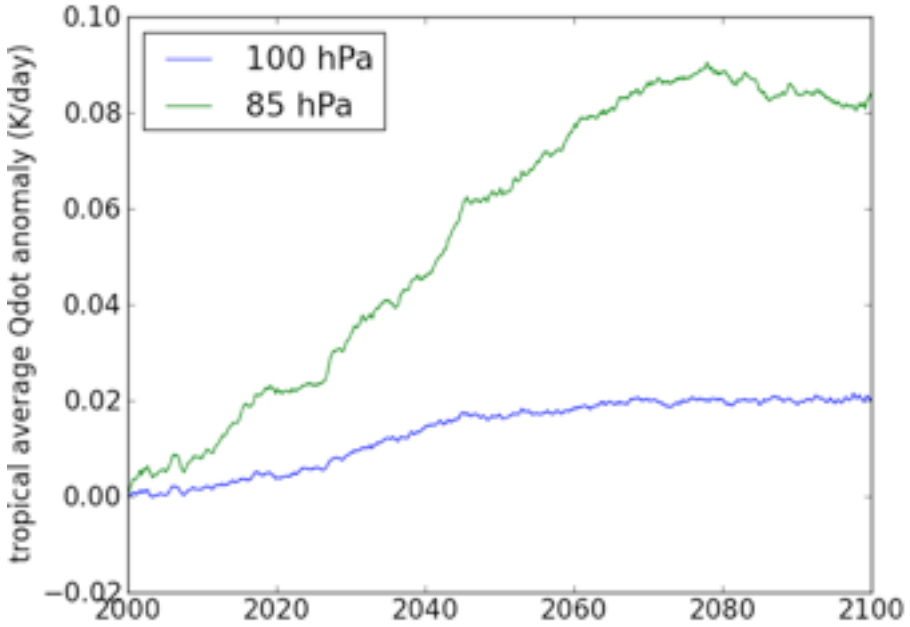
-0.35 ppmv

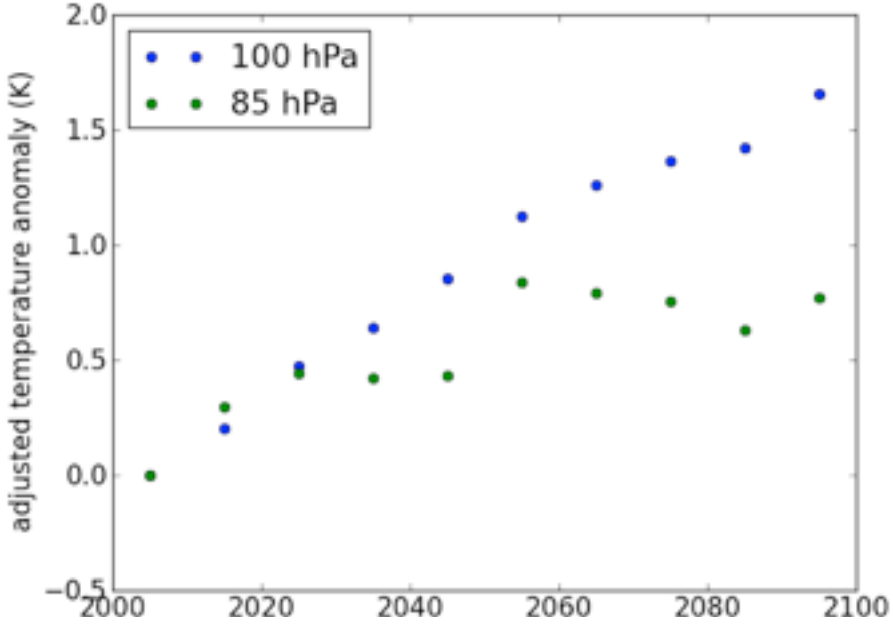
ERAi ΔT = -0.15 K

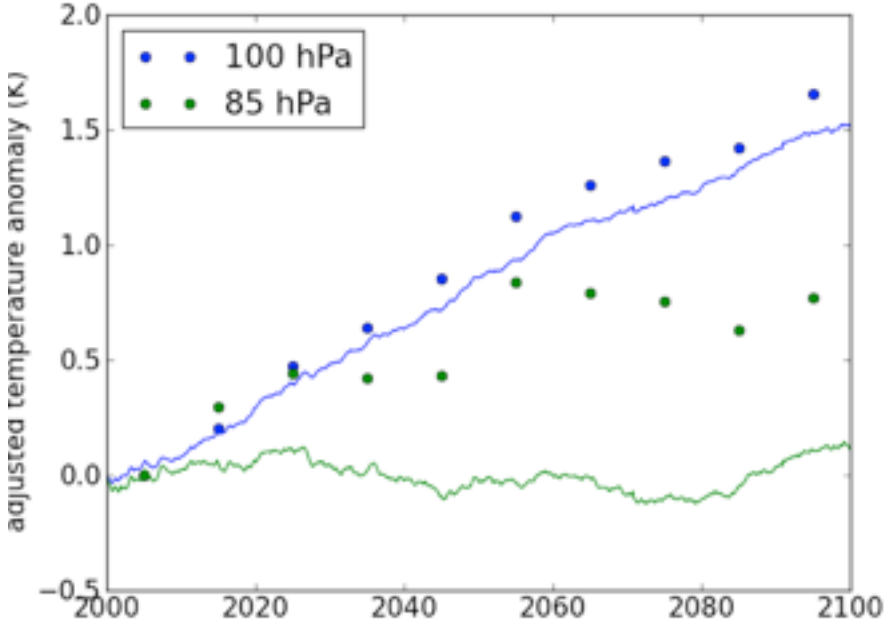


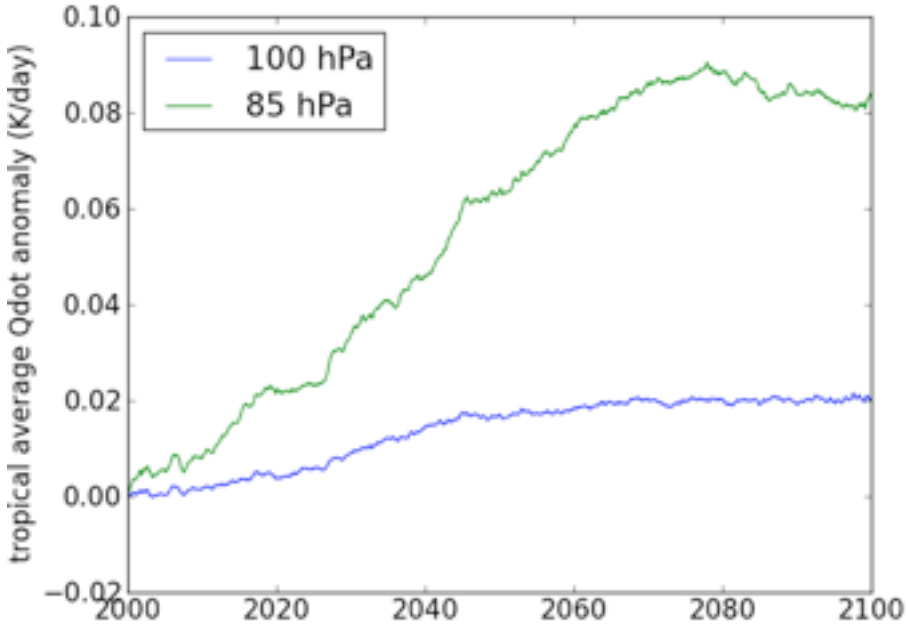
Goddard Chemistry-Climate Model GEOSCCM
Provided by Anne Douglass


100 hPa
85 hPa
tropical average T anomaly (K)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
2000
2020
2040
2060
2080
2100


100 hPa
85 hPa
tropical average Qdot anomaly (K/day)
0.10
0.08
0.06
0.04
0.02
0.00
−0.02
2000
2020
2040
2060
2080
2100







Base state of the TTL is warming

1. warmer troposphere
2. changing GHGs